ER-6102

BRAYTON CYCLE CAVITY RECEIVER DEVELOPMENT

QUARTERLY REPORT

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TRW ELECTROMECHANICAL DIVISION

THOMPSON RAMO WOOLDRIDGE INC.

23555 EUCLID AVENUE ■ CLEVELAND, OHIO 44117

APRIL 1964 – JUNE 1964

JULY 1964 – SEPTEMBER 1964

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RECEIVER DEVELOPMENT

QUARTERLY REPORT

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TRW ELECTROMECHANICAL DIVISION
Thompson Ramo Wooldridge Inc.
Cleveland, Ohio

APRIL 1964 - JUNE 1964
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NOTICE

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INTRODUCTION

This report is presented in two parts; Part I gives the progress obtained during the quarter from April 1964 to June 1964, and Part II explains the progress in the following quarter from July 1964 to September 1964. Part I includes sections 1.0 through 5.0 and Part II consists of sections 6.0 through 8.0. Since section 1.0, Project Objectives, applies to both parts, it is not repeated in Part II. Also, section 5.0, Planned Direction of Effort for the July-September quarter, applies to both parts and is not repeated.

1.0 PROJECT OBJECTIVES

The Brayton cycle cavity receiver development program as presently planned consists of three phases. Phase I is being performed currently and features both a design study of the full-scale flightweight unit and a material compatibility investigation with lithium fluoride as the corrosive salt. Phase II is contemplated to consist of construction and ground test of the flightweight unit. Phase III is planned as the endurance test of the flightweight unit. The ultimate objective of the program is to demonstrate a one year endurance capability of the flightweight unit in a ground test.

2.0 PROJECT OBJECTIVES FOR THE REPORTING PERIOD OF APRIL 1, 1964 THROUGH JUNE 30, 1964 (REPEATED FROM THE PREVIOUS QUARTERLY REPORT)

During the quarter from April through June, effort will be directed towards accomplishing these tasks:

1. Continuation of the first 2500-hour furnace test.

2. Examination and analysis of the two TD nickel capsules removed after the third interruption.

3. Continuation of discussions with NASA on additional corrosion testing and on additional work requested for the design study.

3.0 PROJECT PROGRESS DURING THE REPORTING PERIOD

3.1 The Initial Furnace Test

The initial furnace test, which had been scheduled for 2500 hours, continued during the reporting period. In view of the three previous interruptions, it was mutually agreed by TRW and NASA to continue the test until 5000 hours or a failure occurred. As of midnight June 30, a total of 4,198 hours of testing had been accumulated. The Haynes 25, Haynes 56, Hastelloy X and TD Nickel capsules have been exposed to full test time. The Hastelloy N and Waspalloy capsules have 672 hours less, or a total test time of 3526 hours. Of the total 4198 hours of test time, 2123 hours have been accumulated since the last failure. The heating cycle has averaged 1.009 hours per cycle. The cooling cycle has averaged 0.503 hours per cycle.

The project schedule for Task II, the initial materials corrosion investigation, is shown in Figure 1. The test is continuing.

3.2 Examination and analysis of Failed TD Nickel Capsules

As was stated in the third quarterly progress report, ER-5905, the third interruption to the scheduled 2500 hour test occurred at 2175 hours. After the interruption the capsules were examined using dye penetrant, fluorescent penetrant, and radiographic methods. On the basis of the radiographs, two capsules appeared to be probable failures and were removed from the furnace. These capsules were of TD nickel, nos. 17 and 20. Capsule 17 had both welded end caps and longitudinal seam welds. Capsule 20 had brazed end plugs. Both of these capsules were cut open and visual examination indicated that capsule no. 17 had definitely leaked. The inside tube wall around the longitudinal seam capsule was discolored. Also evidence of corrosive attack to the weld bead, which was Rene 41 material, was found. The tube walls of capsule no. 20 looked absolutely clean.

Metallographic examination of specimens removed from capsule no. 17 revealed a leaching type of attack on the weld bead. This attack ranged in depth up to a maximum of 0.020 inch. The exact point of failure was not located. The TD nickel appeared to be relatively unaffected.

Examination of the tube wall of capsule no. 20 revealed negligible attack, although the braze fillet around both end plugs appeared to be corroded. The attack was in the form of leaching and depletion. The maximum depth of attack was approximately 0.020 inch. However, no evidence of complete penetration was found on the braze fillets on either end plug. Although the braze fillets on this capsule suffered attack, the conclusion was drawn that this capsule did not leak.

In addition, several samples of failed capsules were submitted for electron microprobe analysis to determine the composition of a second phase that was found within the grain boundaries. The specimens submitted for analysis were taken from the following capsules:

1. Capsule No. 2, Rene 41
2. Capsule No. 5, Rene 41
3. Capsule No. 10, Udimet 500
4. Capsule No. 20, TD Nickel.

A complete status report of the capsules placed on test was presented in Table I, page 31, of the Third Quarterly Progress Report, ER-5905.

3.3 Discussions with NASA on Additional Work

During the reporting period, discussions and negotiations were conducted with NASA to specify additional work needed in the design study phase of the receiver/heat storage unit development program. The additional work negotiated included the following items:

1. Task III - Additional Corrosion Tests
2. Amendment No. 4 - Additional Small Scale Experiments
3. Task IV - New Concept Design and Cavity Surface Temperature Distribution.

The effective starting date for Task III was June 1, 1964. The starting date for the other items above is July 1, 1964. Thus, during the first reporting period, work was performed on Task III only. The project schedule for Task III is presented in Figure 2.

As shown in Figure 2, the effort has been devoted to ordering of material and fabrication. The status of the various items as of 30 June 1964 is as follows:

1. Capsule Materials.

   Fabrication of the forty capsules required has been progressing during the month. Their status is as follows:

		Hastelloy N	Hastelloy X	Haynes 25	Incoloy 800	Inconel X	318 S.S.	TD Ni	Waspaloy
Material	on Hand	X	X	X	X	X	X		X
Capsules	Machined	X	X	X	X	X	X		X
	Heat Treat	X	X	X		X			X
	Cleaned	X	X	X					X
	Welded			X					X
	Heat Treat								
	Radiograph								
	Cleaned								
	Loaded								
	Sealed								

2. Capsule Protection Tubes.

All of the material for the outer protection tubes has been received except for the 3/4 inch 316 stainless steel tubing. The tubing is due on July 3.

3. Lithium Fluoride.

Construction of the container for the lithium fluoride is progressing. The container should be ready for shipment by July 10. Before shipment, the welds on the container will be leak tested under both vacuum and helium pressure.

4. Capsule Furnaces.

Both furnaces have been checked out and are ready to operate. The only maintenance required will be the replacement of thermocouples and Globar heating elements. This will not be done until the tests are ready to start.

5. Capsule Container.

Two containers have been fabricated. The only work left is to weld in the capsule hanger tubes. This should be complete by July 10.

6. Leak Detection.

The conductivity controllers and conductivity cells are on order. The cells should be received by July 6. The delivery date for the controllers is August 3. Once the cells are received, they will be mounted on the furnaces so that the only work left will be to attach the leads from the cells to the controllers.

7. Vacuum Chamber.

The materials for the vacuum chamber are on order.

4.0 CURRENT PROBLEM AREAS AS OF 1 JULY 1964

No problem areas exist as of 1 July 1964.

5.0 PLANNED DIRECTION OF EFFORT FOR THE QUARTERLY PERIOD FROM 1 JULY 1964 THROUGH 30 SEPTEMBER 1964

During the period from 1 July 1964 to 30 September 1964, the effort will be directed toward accomplishing these tasks:

1. Completion of the furnace test in Task II.

2. Initiation of both furnace tests in Task III.

3. Start of the testing under Amendment No. 4.

4. Preliminary receiver design to the new specifications of Task IV.

5. Calculation of the bath variable thermal resistance for the cavity surface temperature distribution in Task IV.

6. Control design analysis for the aperture control mechanism in Task IV.

6.0 PROGRESS DURING THE PERIOD FROM 1 JULY 1964 to 30 SEPTEMBER 1964

The technical progress achieved during the above reporting period is presented for each of the task categories currently in operation. These tasks are the following:

Task II - Material Corrosion Testing, One Furnace

Task III - Additional Material Corrosion Testing, Two Furnaces

Amendment 4 - Additional Small Scale Experiments

Task IV - Two Percent Pressure Drop Design, Aperture Control Analysis and Cavity Temperature Distribution.

6.1 Task II Progress

The project schedule for Task II is shown in Figure 1 for 1 July 1964. At that time the remaining activities included completion of the scheduled 5000-hour furnace test and evaluation and analysis of the test capsules. Formal technical direction to terminate the furnace test on Monday, July 20, 1964 was received from the NASA Lewis Research Center. The Tapco Plant of Thompson Ramo Wooldridge began a two-week plantwide vacation shutdown on that date. In addition, all electrical power was to be off for 24 to 72 hours to permit annual electrical power system maintenance. In view of this situation, NASA decided that it was preferable to terminate the test at 4661 hours rather than cool down to room temperature and reheat again when electrical power was available. The average heating time for the cycles in the 4661 hour test was 1.01 hours per cycle. The average cooling time for this test was 0.496 hour per cycle.

After the test was terminated and the capsules removed from the test container, the NASA Project Manager selected six capsules to be sectioned and examined metallographically. The remaining eight capsules containing lithium fluoride plus an empty control capsule were to be included in the first furnace test of Task III. These nine capsules are being tested under Task III and as of midnight September 30 have been exposed to 634 hours of additional test time. The six capsules removed and sectioned are listed in Table I. The remaining nine capsules now being tested under Task III are listed in Table II which also includes the new capsules placed in the test container.

The results of the examination of specimens removed from test after 4661 hours are listed in Table I. Except for Waspaloy Capsule No. 28, the attack experienced was limited to surface roughening and light depletion to the depths indicated in Table I. Photomicrographs illustrating the attack experienced are presented in Figures 3 through 8.

In Figures 5 through 7, (Hastelloy X Capsule No. 24, Haynes Alloy No. 56 Capsule No. 25, and Hastelloy N Capsule No. 30), the surface of the specimen removed from the bottom of each capsule is shown in both the etched and unetched condition. All three alloys showed the presence of a second phase in the unetched condition. Upon etching this phase tended to over-etch and created the appearance of a heavier attack than what occurred.

Figure 8 shows the appearance of the surface of the specimen removed from the top of Waspaloy Capsule No. 28 in both the etched and unetched condition. As shown, the capsule wall suffered a light leaching attack to a maximum depth of 3 mils and depletion to a maximum depth of 5 mils. The most unusual point is that the heaviest attack occurred in the region that, because of the change in volume with temperature, was in contact with lithium fluoride only during the hottest portion of the temperature cycle. The specimen that was removed from the bottom of the capsule, which was in continual contact with the lithium fluoride, showed

Table I - Results of Examination of Alloys Exposed to Lithium Fluoride Between 1500°F and 1850°Test Conditions

Capsule No.	Material	Capsule* Type	Exposure Time	Average Cycle Heat	Temperature (Hr/Cycle) Cool	Results of Examination
16	Haynes Alloy No. 25	ECLSW	4661	1.01	0.496	Light Depletion to 3 Mils. No Preferential Attack to Weld Bead.
19	TD Nickel	ECW	4661	1.01	0.496	Light Depletion to 3 1/2 Mils. Evidence of Grain Recrystallization to Depth of 1 1/2 Mils.
24	Hastelloy X	ECW	4661	1.01	0.496	Light Depletion to 2 Mils.
25	Haynes Alloy No. 56	ECLSW	4661	1.01	0.496	Light Depletion to 1 1/2 Mils.
28	Waspaloy	ECLSW	3989	1.01	0.497	Light Leaching to 3 Mils. Depletion to Maximum Depth of 5 Mils.
30	Hastelloy N	ECLSW	3989	1.01	0.497	Light Depletion to Maximum Depth of 4 Mils.

* EC - End Caps

LS - Longitudinal Seams

W - Welded

Table II - Capsules To Be Placed Into Test in Task III Furnace 1

Capsule No.	Material	Capsule* Type	Filler Material	Remarks
13	Haynes Alloy No. 25	ECW-N	Haynes Alloy No. 25	Carried Over From Task II Furnace 1
14	Haynes Alloy No. 25	ECLSW	Haynes Alloy No. 25	Carried Over From Task II Furnace 1
15	Haynes Alloy No. 25	ECLSW	Haynes Alloy No. 25	Carried Over From Task II Furnace 1
21	TD Nickel	ECB	GE J-8400	Carried Over From Task II Furnace 1
22	Hastelloy X	ECLSW	Hastelloy X	Carried Over From Task II Furnace 1
23	Hastelloy X	ECLSW	Hastelloy X	Carried Over From Task II Furnace 1
26	Haynes Alloy No. 56	ECLSW	Haynes Alloy No. 56	Carried Over From Task II Furnace 1
27	Waspaloy	ECLSW	Waspaloy	Carried Over From Task II Furnace 1
29	Hastelloy N	ECLSW	Hastelloy N	Carried Over From Task II Furnace 1
31	Inconel X-750	ECLSW	Inco 69	
32	Inconel X-750	ECLSW	Inco 69	
35	Inconel X-750	ECW	Inco 69	
36	Inconel X-750	ECW	Inco 69	
41	Hastelloy X	ECLSW-BNF	Hastelloy X-GEJ8102	
42	Hastelloy X	ECLSW-BNF	Hastelloy X-GEJ8102	
43	Hastelloy X	ECLSW	Hastelloy X	
44	Hastelloy X	ECLSW	Hastelloy X	
49	Haynes Alloy No. 25	ECLSW-BNF	Haynes 25 - GEJ8102	
50	Haynes Alloy No. 25	ECLSW-BNF	Haynes 25 - GEJ8102	
51	Haynes Alloy No. 25	ECLSW	Haynes Alloy No. 25	

Table II (continued)

Capsule No.	Material	Capsule* Type	Filler Material	Remarks
52	Haynes Alloy No. 25	ECLSW	Haynes Alloy No. 25	
57	Haynes Alloy No. 25	ECW	Haynes Alloy No. 25	Thermocouple Capsule
59	Incoloy 800	ECLSW	Inco 62	
60	Incoloy 800	ECLSW	Inco 62	

*EC - End Caps

LS - Longitudinal Seams

W - Welded

N - Not Filled with Lithium Fluoride (Blank Capsule)

BNF - Internally Brazed Nickel Fins

B - Brazed

essentially the same type of attack except the depths were limited to 1 and 4 mils, respectively.

Four capsule specimens taken from previously failed capsules were submitted for electron microprobe analysis. The results of the analysis of the specimens are shown in Table III and are discussed below.

<u>Rene' 41 Capsule 2, Section 3 - 1327 hours</u>

Metallographic examination revealed a light attack in the form of leaching to a depth of 0.001 inch. The results of the microprobe indicated a light depletion type of attack to a maximum depth of 0.004 inch. In general, the concentrations of aluminum, nickel and titanium were found to be relatively lower and the concentrations of molybdenum, cobalt and chromium relatively higher within the 0.004 inch surface band compared to the normal matrix. In addition, the microprobe results indicated the presence of titanium and aluminum-rich precipitates within this 0.004 inch band.

<u>Rene' 41 Capsule 5, Section 3 - 672 hours</u>

Metallographic examination of the specimens removed from the capsule revealed attack in the form of leaching and depletion to depths from 0.001 inch at the top to 0.005 inch at the bottom. However, there appeared to be a second phase present in the grain boundaries of the specimen removed from the top of the capsule. This grain boundary effect appeared to a depth of 0.009 inch. Microprobe analysis of this specimen revealed compositional changes to a depth of 0.008 inch. In general, as shown in Table III, the concentrations of aluminum, nickel, molybdenum and titanium were lower and the concentrations of cobalt and chromium relatively higher within this region as compared to the matrix.

Table III - Results of Electron Microprobe Analysis

Specimen	Ni	Cr	Fe	Co	Mo	Al	Ti	Other
	Composition w/o							
Rene' 41 Capsule 2, Sect. 3								
Matrix	53	19	--	11.0	9.8	1.7	3.2	--
Reaction Zone	51.5-53	19-20.5	--	11.0-11.5	9.8-10.5	0.5-1.7	2.9-3.2	--
Rene' 41 Capsule 5, Sect. 3								
Matrix	53	19	--	11.0	9.8	1.7	3.2	--
Reaction Zone	44.6-53	19-21	--	11.0-24.0	5.0-9.8	0.6-1.7	1.6-3.2	--
Grain Boundary Ppt.	21-24	15-17	--	9-11	42-45	0.5	4-6	3-5 W
Udimet 500 Capsule 10, Sect. 2								
Matrix	48.9	18.5	4	18.5	4	3	3	
Reaction Zone	48.9-52.5	18.5-19.5	4.0-5.9	18.5-19.7	4.0-4.7	0.5-3	2.5-3	
TD Nickel Capsule 20, Sect. 4								
Matrix	98.5							1.5 Th
Reaction Zone	98.5							1.5 Th

A discrete point-analysis was conducted on the second phase found within the grain boundaries. This phase was found to be enriched in molybdenum and also contained some tungsten. The nominal composition of the phase is shown in Table III. In general, the phase appears to be either of the MoNi type where tungsten and chromium substitute for molybdenum and titanium and cobalt substitute for nickel, or it may be a carbide of the M_6C type.

Udimet 500, Capsule 10, Section 2 - 1327 hours

Previous examination of the specimen revealed a leaching type of attack to a maximum depth of 0.004 inch. The results of the microprobe analysis on this specimen revealed compositional changes to a maximum depth of 0.008 inch. In general, within this region, the concentration of titanium and aluminum were found to be slightly lower and the concentration of molybdenum, cobalt, chromium, iron and nickel relatively higher as compared to the normal matrix.

In addition to the leaching attack incurred, the presence of a second grain boundary phase was noted in the specimen. This phase appeared to a maximum depth of 0.002 inch. Analysis of this phase indicated it to be enriched in aluminum and titanium.

During the analysis, the phase fluoresced an incandescent violet. This type of fluorescence is typical of oxides.

TD Nickel Capsule 20, Section 4 - 2175 hours

Previous metallographic examination revealed attack in the form of surface roughening and pitting to a maximum depth of 0.001 inch. The microprobe analysis revealed no significant changes in composition for either nickel or thorium from the matrix out to the surface. A constant value of 1.5 w/o thorium was noted throughout the sample. An incandescent violet fluorescence was noted in the sample. As discussed before, this fluorescence is indicative of the presence of oxides.

From the results obtained, there is some indication that leaching of aluminum, titanium, nickel and, in one case, molybdenum has occurred. At the present time, it is felt that there is not enough data available to be specific. Part of the composition changes that occurred in the specimens could have resulted from metallurgical changes such as precipitation of intermetallic compounds. However, in the light of the above results, further studies are being conducted in an attempt to determine if the chemistry changes are the result of corrosive attack. Three more specimens are being submitted for microprobe analysis. These specimens are from TD Nickel Capsule No. 19, Hastelloy X Capsule No. 24 and Waspaloy Capsule No. 28. Also, the lithium fluoride from the capsules is being analyzed spectrographically to determine the presence of metallic corrosion products.

6.2 Task III Progress

The project schedule for Task III is shown in Figure 2 as of 1 July 1964. As indicated in Figure 2, the operation of furnace number 1 was scheduled to start on or about 1 August. However, a snag developed in the capsule preparation as it became impossible for TRW to obtain the contractually specified lithium fluoride. An alternate source of purified lithium fluoride was located and relief requested from the contractual requirement. The relief was granted by NASA on 12 August and authority given to procure purified lithium fluoride from the Harshaw Chemical Company. The analysis of the lithium fluoride according to Harshaw is as follows:

Impurity	Quantity
Fe	1 ppm
Al	1 ppm
Ca	1 ppm
Mn	1 ppm
Si	1 ppm
Cr	Not detected
Ni	Not detected

Harshaw is not equipped for sulfur, water and hydrogen fluoride analyses but offered the following comments:

1. Water and hydrogen fluoride should be nil since there is no absorption in the infra-red spectra at the points where these compounds would appear.

2. Sulfur may or may not be present in minute quantities. There is absorption in the infra-red spectra at the point where sulfur would appear, but the hydroxylion also causes absorption at the same point. Harshaw feels that the absorption is more likely caused by hydroxyl than by sulfur but would not make a claim past this point.

Three pounds of lithium fluoride of 99.9+% purity were received from the Harshaw Chemical Company on 24 August. This material is stored in a vacuum oven attached to a drybox under a vacuum of 10^{-3} mm Hg at a temperature of 120°C. The capsules needed for the first furnace test of Task III, listed in Table II, were loaded with lithium fluoride in the above dry box under argon cover gas of 99.998% purity. After loading the top end cap was welded to the capsules and the capsules sealed in another drybox with the same type of cover gas. Each of the test capsules were enclosed in a 316 stainless steel container which acts as a shield to protect the test capsules from external fluoride attack when another capsule fails. The new test capsules with their stainless steel shields and the nine capsules from the furnace test of Task II were mounted in the conventional Hastelloy X test container, the container sealed and inserted in the furnace. The test was started on 4 September 1964 and is scheduled as a 5000 hour test. As of midnight on 30 September, 634 hours of testing time had elapsed. The average heating time was 1.5 hours per cycle, and the average cooling time was 0.52 hour per cycle.

The four alloys initially inserted in the furnace test of Task II have a combined testing time of 5295 hours. The two alloys inserted at the end of 672 hours have a combined testing time of 4623 hours.

The second furnace test of Task III was scheduled to start on or about 1 September. The lack of purified lithium fluoride delayed the start of this furnace test also. The capsules to be tested were prepared according to the contract specifications, but formal direction to change the type of capsules was received on 22 September. At the time of receipt of the change, it was estimated that the second test would start late in September. As a result of the change, it is now estimated that the second furnace test will start in mid-November. The status and revised capsule lineup for test number 2 of Task III is listed in Table IV.

6.3 Amendment No. 4 Progress

The objective of the work effort specified in Amendment 4 is to provide additional data on the heat input and heat release characteristics of lithium fluoride. Five additional modules are to be constructed and tested. Also, two dummy modules are

Table IV - Status of Capsules for Furnace 2, Task III

Capsule No.	Material	Type*	Status
33A	Inconel X-750	ECW	In Fabrication
37	Hastelloy N	ECLSW	Loaded
38	Hastelloy N	ECLSW	Loaded
39	Hastelloy N	ECW	Loaded
40	Hastelloy N	ECW	Loaded
45	Hastelloy X	ECLSW	Loaded
47	Hastelloy X	ECW	Loaded
55	Haynes Alloy No. 25	ECLSW	Loaded
56	Haynes Alloy No. 25	ECLSW	Loaded
57	Haynes Alloy No. 25	ECWTC	Loaded
58	Haynes Alloy No. 25	ECW	Loaded
62	Incoloy 800	ECW	Loaded
64	318 Stainless Steel	ECLSW	Loaded
65	318 Stainless Steel	ECW	Loaded
67	Waspaloy	ECLSW	Loaded
68	Waspaloy	ECW	Loaded
69	Waspaloy	ECW	Loaded
70	Waspaloy	ECLSW	Loaded
71	Waspaloy	ECLSW	In Fabrication

Table IV (continued)

Capsule No.	Material	Type*	Status
72	Waspaloy	ECWBNF	In Fabrication
73	Waspaloy	ECWBNF	In Fabrication

*Type

EC - End Caps
LS - Longitudinal Seams
W - Welded
TC - Internal Thermocouple
BNF - Internal Brazed Nickel Fins

defined whose purpose is to permit a test demonstration of controlled freezing patterns prior to testing the last two modules. The modules required are listed in Table V. below.

The material for construction of all modules is Haynes Alloy 25.

The project schedule for the Amendment 4 work is presented in Figure 9. Prior to the start of fabrication, a formal test plan for modules A, B and C was prepared and submitted to NASA for approval. Approval was granted subject to the addition of two thermocouples near the edges of the top and bottom plates. The purpose of the additional thermocouples is to get a better idea of the thermal gradients in the top and bottom plates. Figure 10 is a photograph of module A just prior to joining it to the fluoride loading hopper. The added thermocouple wells on the top and bottom plates required by NASA can be observed.

Figure 11 is a photograph of the test assembly prior to the installation of the Min-K insulation. The module and loading hopper, the module heater reflector, the hopper heater reflector, the hopper fill port (the larger flange) and the hopper view port can be readily identified. Other parts in the photograph include the hopper-module support frame, the main outer support frame (with the Marinite sheets attached) and the rotating fixture. Another view of the test assembly after most of the high temperature insulation was installed is shown in Figure 12. Figure 13 shows the test assembly rotated on its side in the position for the initial melting and subsequent transfer of the lithium fluoride.

The top plates of modules B and C are presented in Figure 14 after the nickel fins were brazed the first time. Close examination of the brazed joints revealed that the braze material did not flow completely under all of the fins

Table V - Module Configurations

	Type	Fins	Remarks
A.	Heat Transfer	None	Basic Configuration
B.	Heat Transfer	3.8% - Nickel	
C.	Heat Transfer	7.6% - Nickel	
D.	Heat Release	None	Basic Configuration
E.	Heat Release	(*)	* To be Determined

to give acceptable fillets on both sides. Consequently, a second brazing operation was performed and the completed plates were examined and approved by the NASA Project Manager. These plates have been assembled into the two modules and as of 30 September both module B and module C are complete in the same condition as module A was for Figure 10.

Several last minute fabrication difficulties caused a schedule slippage of one week. Rig installation and shakedown problems caused a further slippage of one week, making a total slippage of two weeks in the schedule.

The testing of module A was initiated on 10 September and is complete as of 30 September. Data reduction is in process and the module will not be removed from the test rig until the test results are available and can be verified as valid.

One of many rig problems which were encountered during the test program was an air leak into the system. It was known that the vacuum on the system was becoming less effective as the test continued. Finally, all attempts to operate under a vacuum were abandoned in one series of tests, and argon cover gas was introduced. The test was later stopped, the bulk insulation removed and the system sniffed for leaks when argon gas was in the system. One of the bolts on the fill port flange was loose and a leak was detected at the ring joint. A considerable amount of scale was observed in the hopper and on the thermocouple wells attached to the fill port flange. Figure 15 is a closeup view of the fill port and flanges and illustrates the type of scale encountered. Examination of the fluoride transfer tube indicated scale or foreign matter adhering to the sides of the transfer tube.

6.4 Task IV Progress

The Task IV work effort consists of three parts:

1. Two percent allowable gas pressure drop full scale cavity receiver design.
2. Aperture control analysis.
3. Cavity temperature distribution.

Each of these parts will be discussed in order. The project schedule for Task IV is shown in Figure 16.

6.4.1 Two Percent Pressure Drop Design

During the first portion of the design study, it was shown that a full scale receiver design with a two percent allowable gas pressure drop was potentially possible. The weight penalty as indicated by Figure 16 of the third quarterly progress report, ER-5905, was relatively mild. On this basis, NASA directed that a design should be made for this condition.

The first choice for an optimized design was a heater featuring a mean gas Reynolds number of 5500. The number of tubes corresponding to this Reynolds number was 70 with a tube inner diameter of 0.693 in. and a tube length of 69.5 in. These dimensions permitted a storage bath with a 4.5 ft diameter cavity. As a result, the maximum receiver diameter, which determines the amount of collector shadowing, was less than 5 ft.

A potentially dangerous problem area was uncovered in this design, however. In the final version of the four percent design and in this initial version of the two percent design, curved tubes are employed to permit use of maximum length tubes for a given cavity diameter. Although the degree of curvature is slight over most of the tube length, higher degrees of curvature are required at the inlet and outlet headers. It has been ascertained from the literature that the effect of the curvature is to increase the range of Reynolds numbers in which laminar and/or transitional flow can occur. Thus, the transitional Reynolds number from laminar to turbulent flow is increased. The potential problem area arises because the two percent design tends to obtain optimum geometries at a lower gas Reynolds number than the four percent design. The two percent design optimum gas Reynolds number appears to be very close to the transitional Reynolds number, a highly undesirable situation.

The seriousness of this situation is illustrated in Figure 17. The transitional Reynolds number defined as $R_{E_{CRIT}}$ is a function of the ratio of the flow passage radius to the radius of curvature. The line shown is a plot of the equation of Reference 1, and the data are taken from References 2 and 3. Reference 1 indicates that for a Reynolds number of 5500 the critical transitional radius ratio is 0.0172. Thus, for the initial two percent design, any radius ratio above 0.0172 would indicate laminar flow. However, Reference 4 indicates the critical transitional radius ratio is 0.014 for a gas Reynolds number of 5500. Since the initial two percent design indicated an actual radius ratio of 0.013, the gas flow might be just barely turbulent.

To assess the magnitude of the problem, if the initial design were operating in laminar flow, it was assumed that the heater was operating in the laminar regime and the resulting heat transfer and pressure drop calculated. As expected the pressure drop decreased from the design value to about one-third of the design value, and the outlet gas temperature dropped from 1950°R to 1716°R. These values correspond to gas temperature increases within the receiver of 504°R and 270°R.

It is readily apparent that such a situation could not be tolerated.

Therefore, a second design was initiated. The Reynolds number was increased to a mean value of 8100. The number of tubes corresponding to this Reynolds number was 30 with a tube inner diameter of 1.050 inches and a tube length of 113 inches. The basic configuration for both designs was presented as Figure 12 of ER-5905 and is repeated herein as Figure 18.

List of References

Ref. 1 - H. Itō, Friction Factors for Turbulent Flow in Curved Pipes, Journal of Basic Engineering, June 1959. ASME Paper No. 58-SA-14.

Ref. 2 - Data of Taylor as found in McAdams, Heat Transmission, McGraw-Hill Book Company, Third Edition, 1954, page 151.

Ref. 3 - Data of White as found in McAdams, Heat Transmission, McGraw-Hill Book Company, Third Edition, 1954, page 151.

Ref. 4 - Formula of Drew as found in McAdams, Heat Transmission, McGraw-Hill Book Company, Third Edition, 1954, page 151.

6.4.2 Aperture Control Analysis

During this quarter, the temperature and aperture control mechanisms were redesigned to obtain more reliability by using simple linkages and by reducing mechanical frictional pivots and contacts to an absolute minimum. The revised system is shown in Figure 19.

Cavity surface temperature is controlled by four louvers which when open allow reradiation to space. The louvers are actuated by temperature sensitive bulbs located on the cavity surface of the receiver. As the temperature of the sensors increases, the pressure of the liquid metal fluid in the bulbs increases and displaces a pair of bellows on each end of the louvers. Either pair of these bellows can actuate the louvers. The louvers rotate on flexural pivots, thereby eliminating the high temperature bearing lubrication problem.

The aperture cover is actuated in the same manner as the temperature control system.

The mechanical elements for these mechanisms were optimized to obtain the best mechanical arrangement and to satisfy the high temperature and low vacuum environments required. Detailed design was started on matching spring rates of the springs, bellows, pivots and differential pressure characteristics of the liquid metal bulb actuators. Stress analysis of critical sections is being conducted to insure the required strength and cycle life. Material selection will be based on the results of the stress analysis and material compatibility with the working fluid.

6.4.3 Cavity Performance Analysis

The general objective of this portion of the work effort is to determine the performance of the cavity as a receiver and aid in obtaining optimum performance. In addition, the resulting temperature distributions of the inner cavity wall, of the lithium fluoride storage bath and of the gas working fluid are to be evaluated as a function of time in the orbital period and collector orientation to the sun.

The efforts to date have been directed to a review of existing cavity analyses and computerized programs to determine the extent of usefulness and adaptability to the present program objectives. To meet these objectives requires the integration of the heat transfer mode through the thermal heat storage material in the receiver cavity analysis. In this manner, the flux and temperature of discrete elements of area on the receiver cavity surface are determined by an overall energy balance involving all modes of energy exchange from the surface. Thus, this analysis is not limited to assignment of an assumed surface temperature distribution.

Analytical investigation of the heat transfer characteristics of the lithium fluoride storage medium was initiated and completed for the freezing of the medium during the shade portion of the orbit. The method employed was developed on the Sunflower program and consists of an electric analog in which the physical model was reproduced on "Teledeltos" electrical conducting paper. A voltage potential is applied between the source and sink, and lines of constant potential, corresponding to isotherms, can be identified. With knowledge of location of an isotherm relative to the melt line, the position of the melt line at some later time can be determined because it can be shown that the distance which the melt line moves is inversely proportional to the local distance from the melt line to the isotherm.

Several melt line positions were determined as illustrated in Figures 20 and 21. At each melt line position, the electrical resistance from the melt line to the tube wall and the amount of lithium fluoride frozen were measured. The electrical resistance can be readily converted to a geometrical resistance factor. The results are shown in Figure 22.

The final freeze pattern and lithium fluoride volume distribution of solid and liquid provide the starting point for the electric analog simulation of heat addition through the inner shell, corresponding to the sun portion of the orbit. This will be initiated in the next reporting period and combined with receiver characteristics to define the ratio of heat input to heat abstraction through the tube as a function of time and position in orbit. In this phase a major problem will be defining the volume distribution of liquid lithium fluoride as the melt progresses because of the large difference in density between the liquid and solid phases.

The existing computer programstreating the internal distribution of solar flux have been reviewed and changes required to meet the present program objectives identified. The present program treats an axially symmetric concave chamber whose internal wall temperatures and surface properties are given. The program assumes the radiation in the cavity may be separated into a solar and thermal component, and for each component, absorption and emission are Lambertian. The radiosity of each zone and the net flux into each zone are obtained for the solar and thermal components and for the total radiation. The changes to the program required essentially entail including the heat transfer from finite surface areas through the lithium fluoride heat storage medium and the calculation of surface temperatures based upon the net heat exchange. For the misorientation cases, a more extensive modification will be required due basically to the unsymmetrical solar flux distribution on the cavity surface. The current program provides for the calculation of net exchange factors between symmetrical zones of latitude relative to the optical axis. The case of unsymmetrical flux distribution will require, in addition, identification of zones of longitude and calculation of the net exchange factors between all zones.

7.0 CURRENT PROBLEM AREAS

The current problem areas are schedule slippages in two tasks:

1. Task II - The test in furnace number 2 will be delayed six weeks because of the requirement to test three additional Waspalloy capsules.

2. Amendment 4 - The testing of module A was completed about two weeks behind schedule. It is hoped that a gradual return to schedule can be achieved.

8.0 PLANNED DIRECTION OF EFFORT FOR THE NEXT QUARTER

During the next quarter, the effort will be directed toward the following:

1. Continued examination of the failures encountered in Task II.
2. Continuation of furnace test no. 1 in Task III.
3. Initiation of furnace test no. 2 in Task III.
4. Continuation of the small scale experiments under Amendment 4.
5. Completion of the two percent gas pressure drop cavity receiver design layout under Task IV.
6. Continuation of the cavity temperature distribution calculations under Task IV.
7. Completion of the aperture control design analysis under Task IV.

PROJECT SCHEDULE FOR TASK II, THE MATERIALS CORROSION INVESTIGATION

PROJECT TITLE: Lithium Fluoride Corrosion and Material Compatibility Investigations

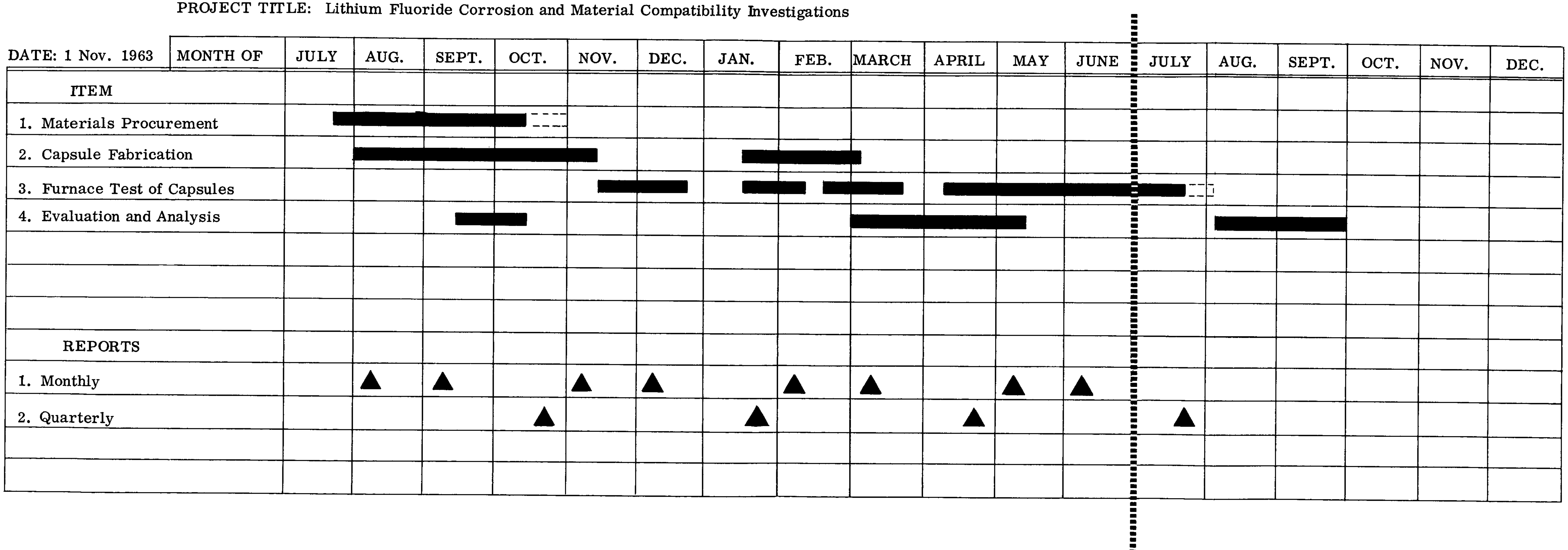


FIGURE 1

PROJECT SCHEDULE, TASK III, ADDITIONAL CORROSION TESTING

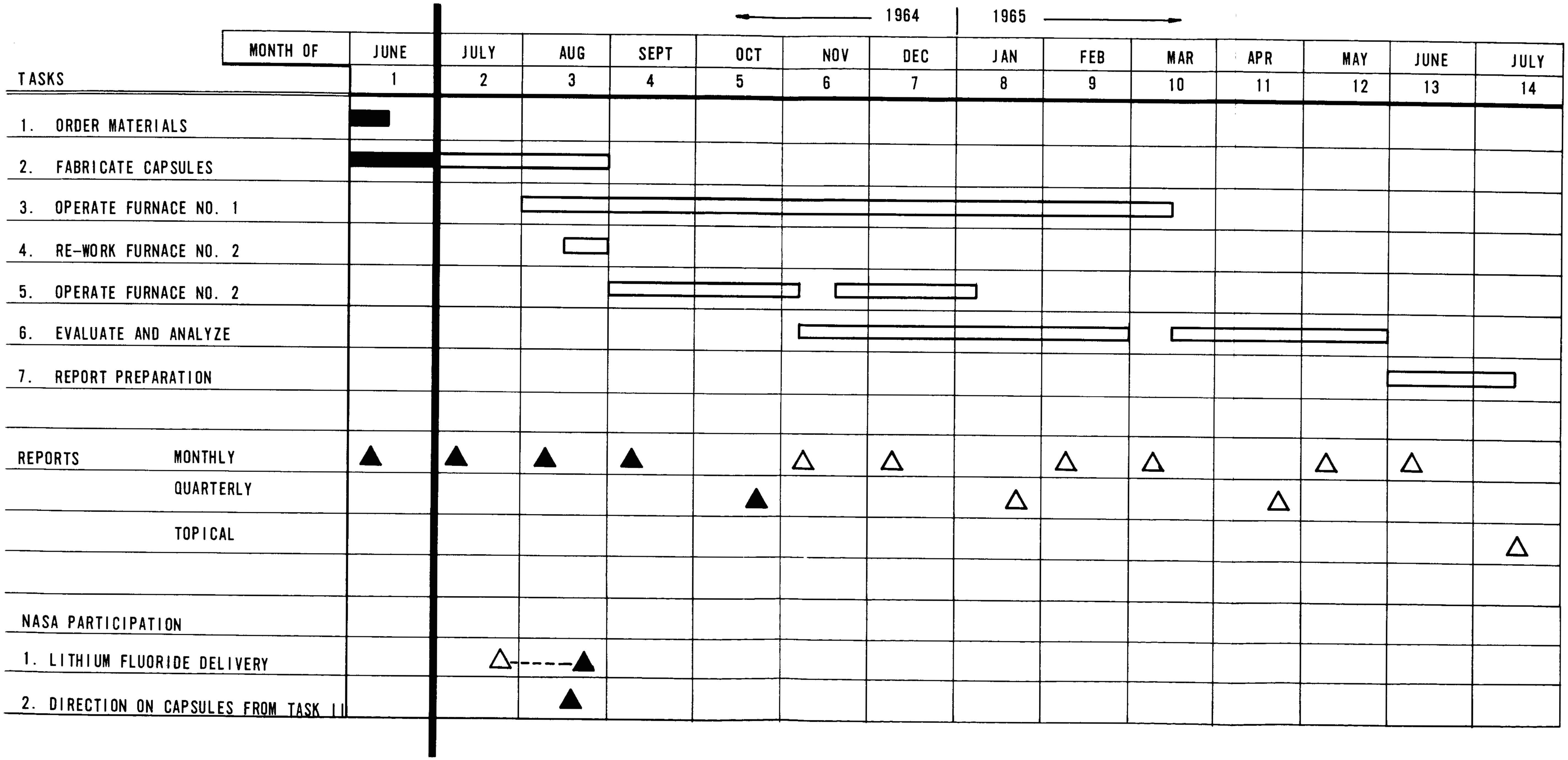
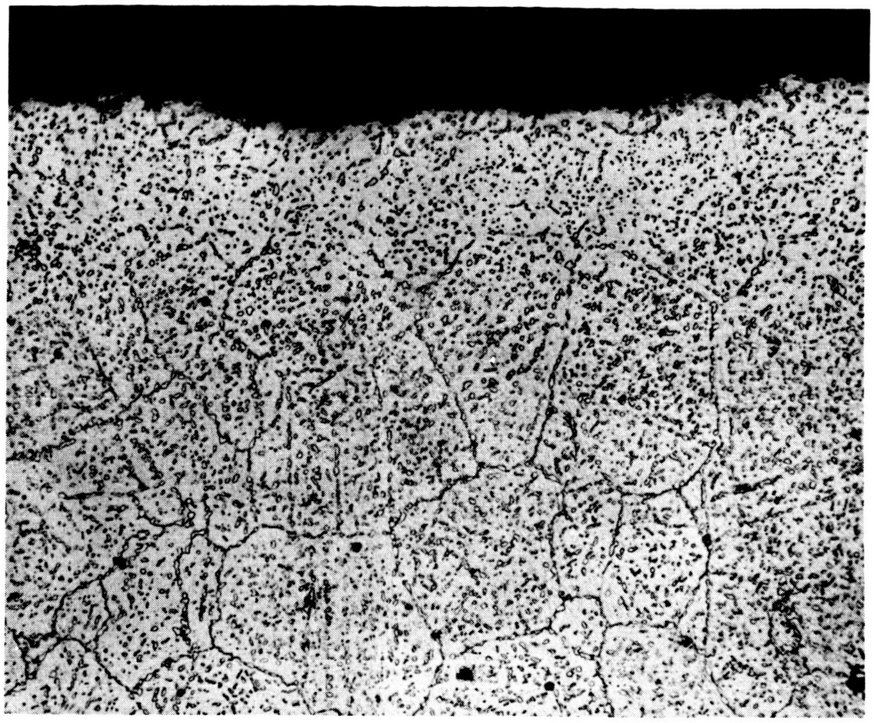
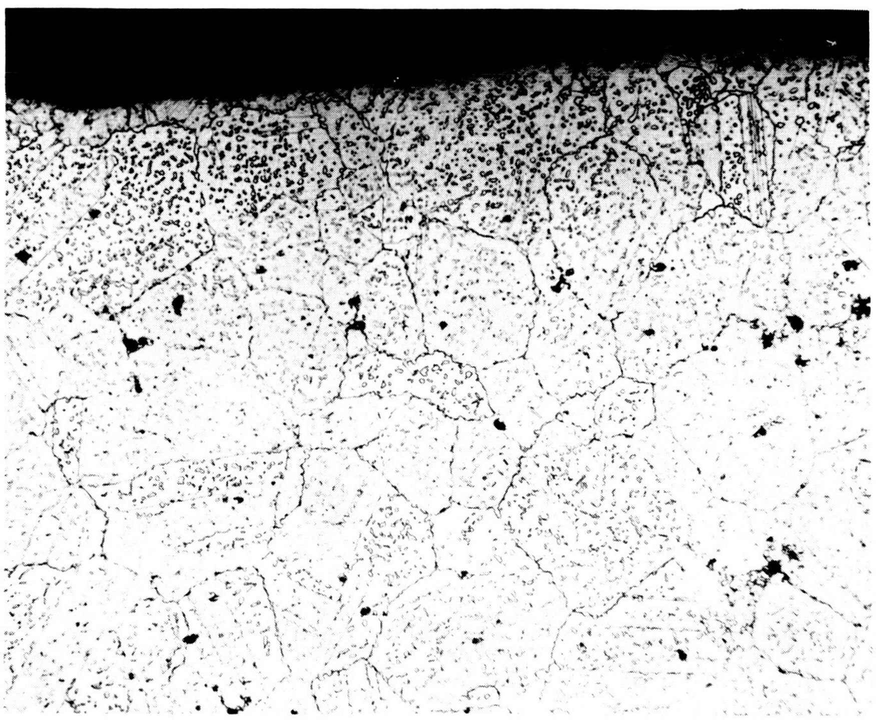


FIGURE 2



RDM A418 250X

BOTTOM OF CAPSULE



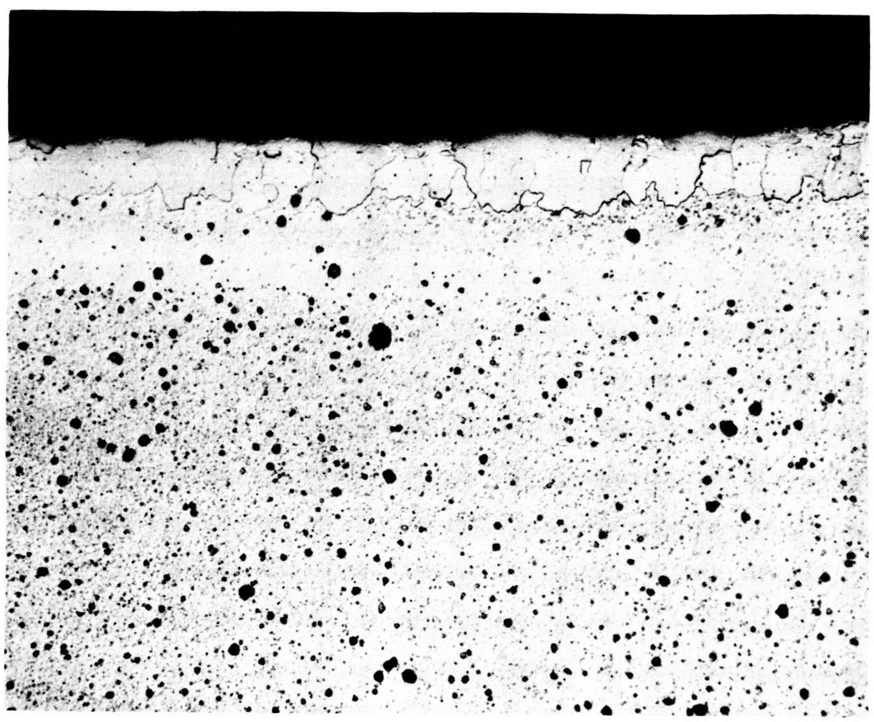
RDM A419 250X

Photomicrographs of the Specimens Removed from
Haynes Alloy No. 25 Capsule No. 16.
Etchant: H_2O_2 + HCl

FIGURE 3

RDM A422 250X

TOP OF CAPSULE

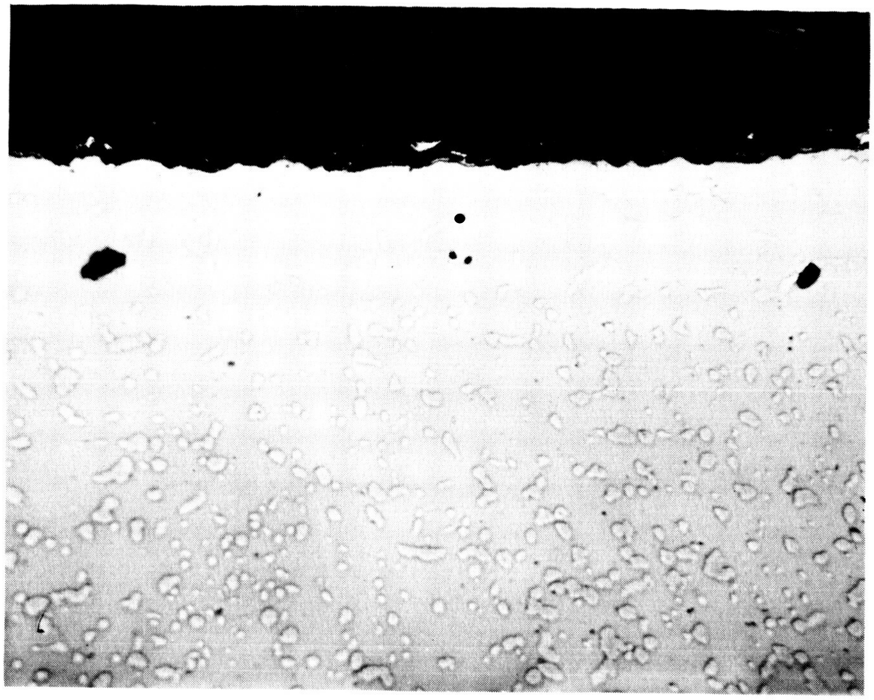


RDM A421 250X

BOTTOM OF CAPSULE

Photomicrographs of Specimens Removed from
TD Nickel Capsule No. 19.
Etchant: 10% Ammonium Persulfate
10% Potassium Cyanide

FIGURE 4



RDM A671 250 X

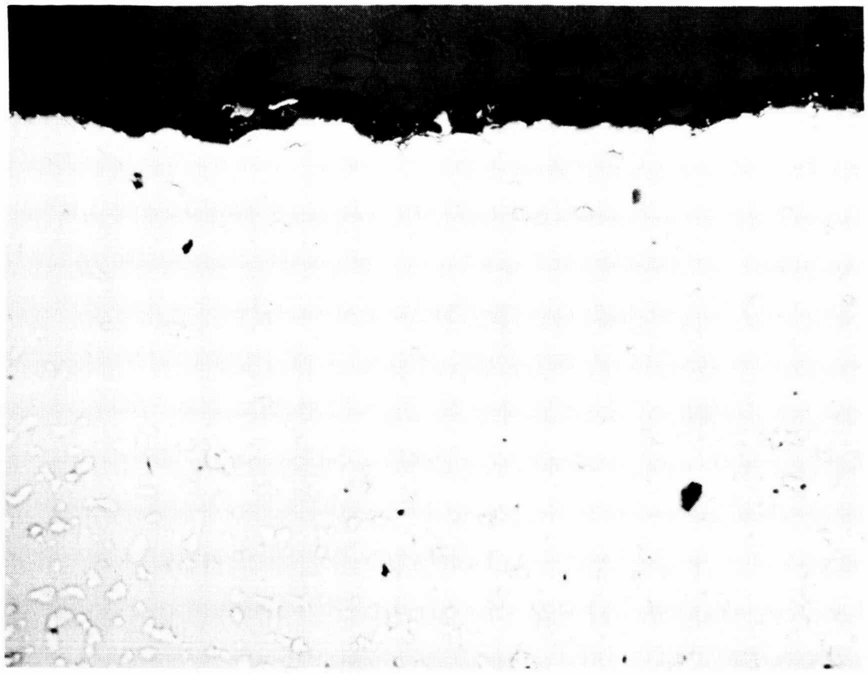
Etchant: None

RDM A431 250 X

Etchant: Electrolytic
10% Oxalic Acid

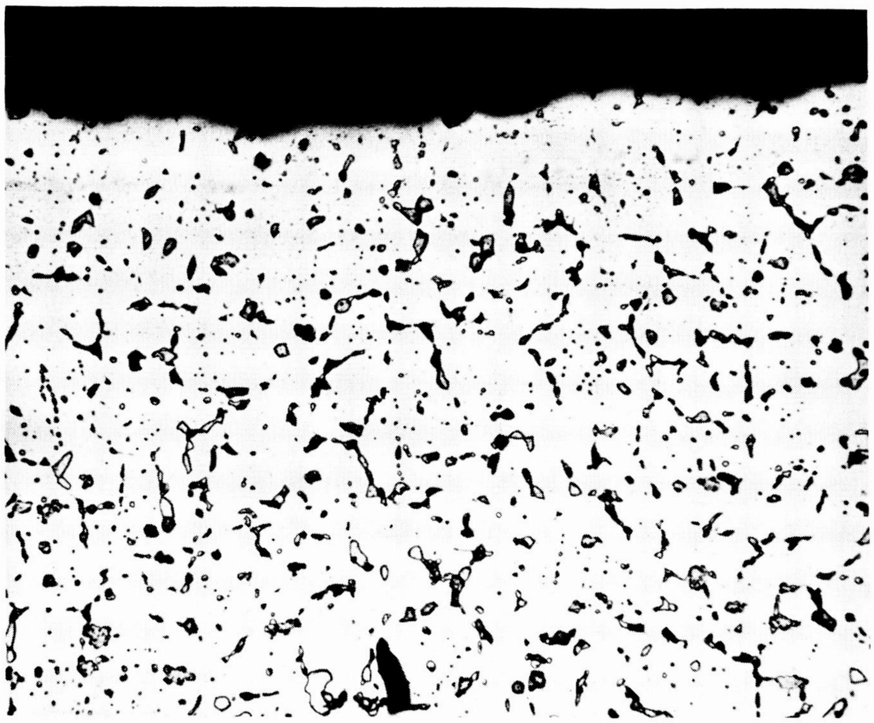
Photomicrographs of the Specimen Removed from the Bottom of Hastelloy X Capsule No. 24.

FIGURE 5



RDM A673 250 X

Etchant: None

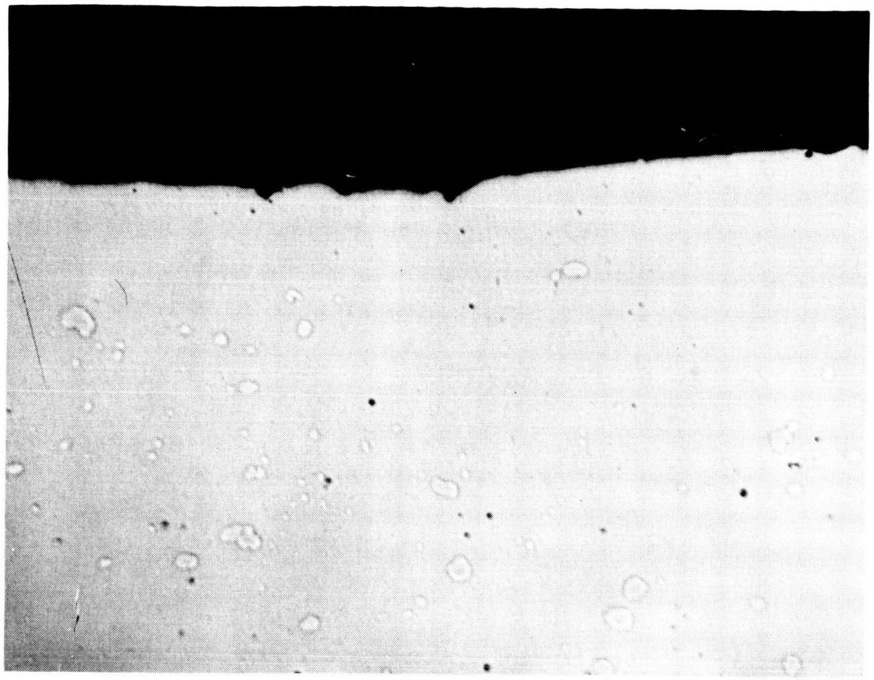


RDM A427 250 X

Etchant: Electrolytic
10% Oxalic

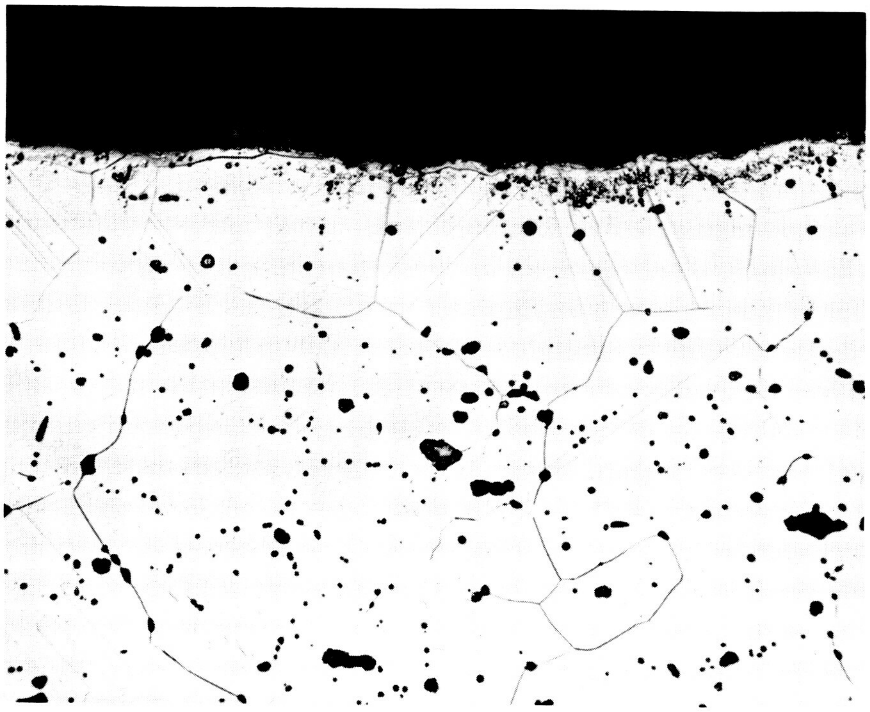
Photomicrographs of the Specimen Removed from the Bottom of Haynes Alloy No. 56 Capsule 25.

FIGURE 6



RDM A677 250 X

Etchant: None

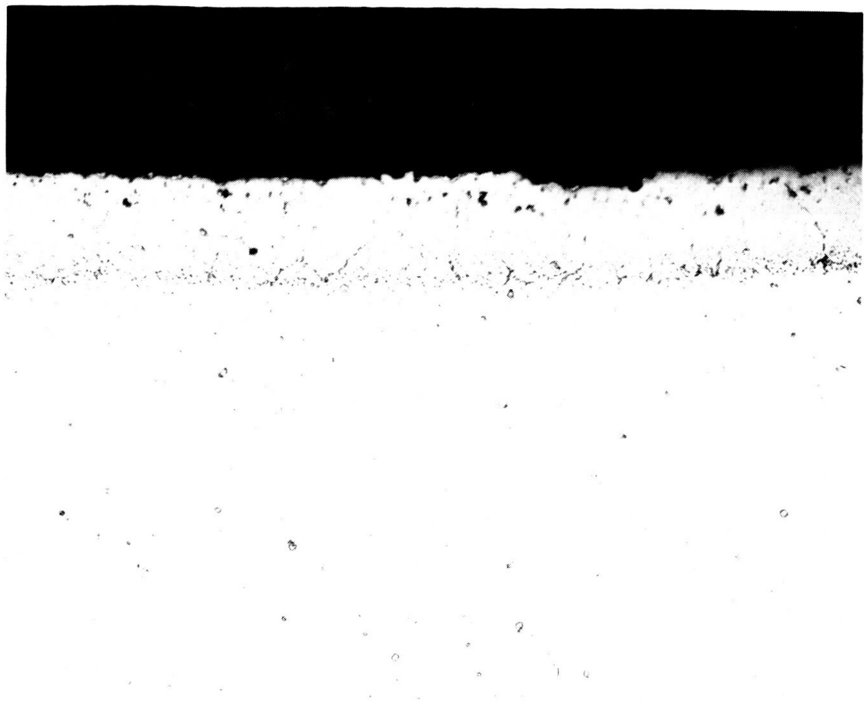


RDM A429 250 X

Etchant: Electrolytic
10% Oxalic Acid

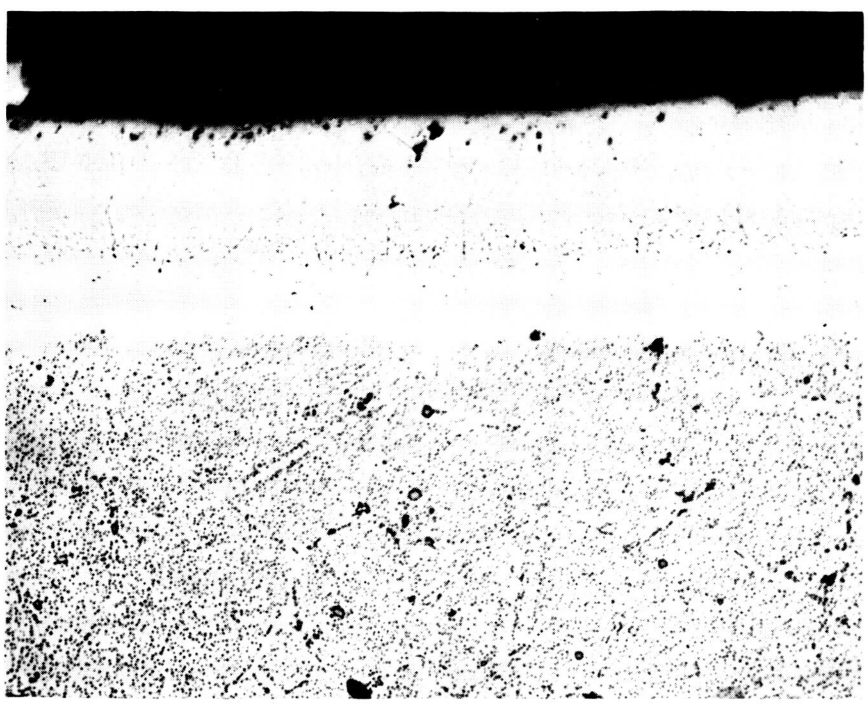
Photomicrographs of the Specimen Removed from the Bottom of Hastelloy N Capsule No. 30.

FIGURE 7



RDM A676 250 X

Etchant: None



RDM A425 250 X

Etchant: Refractory Metals' Etch

Photomicrographs of the Specimen Removed from the Top of Waspaloy Capsule No. 28.

FIGURE 8

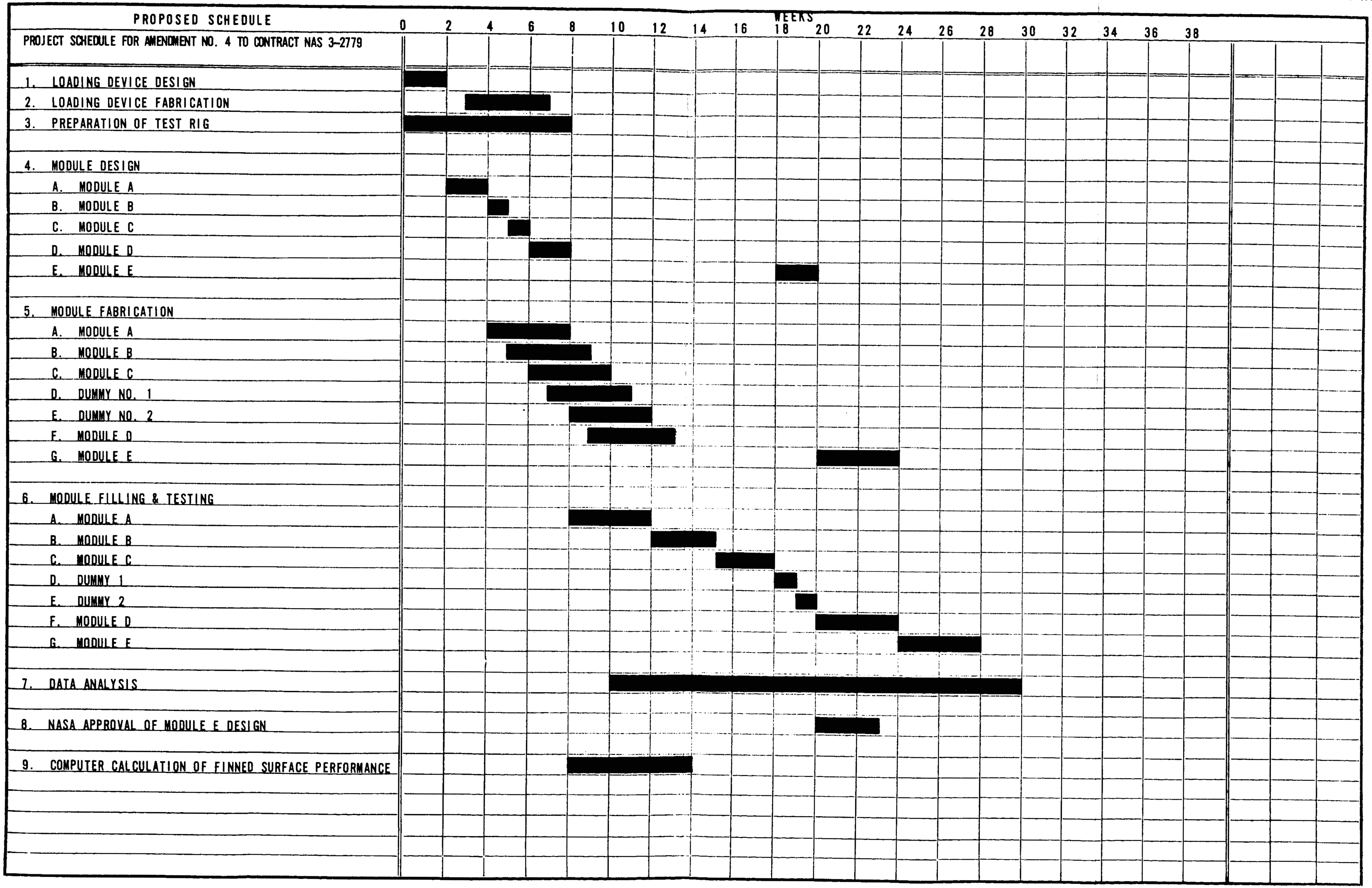
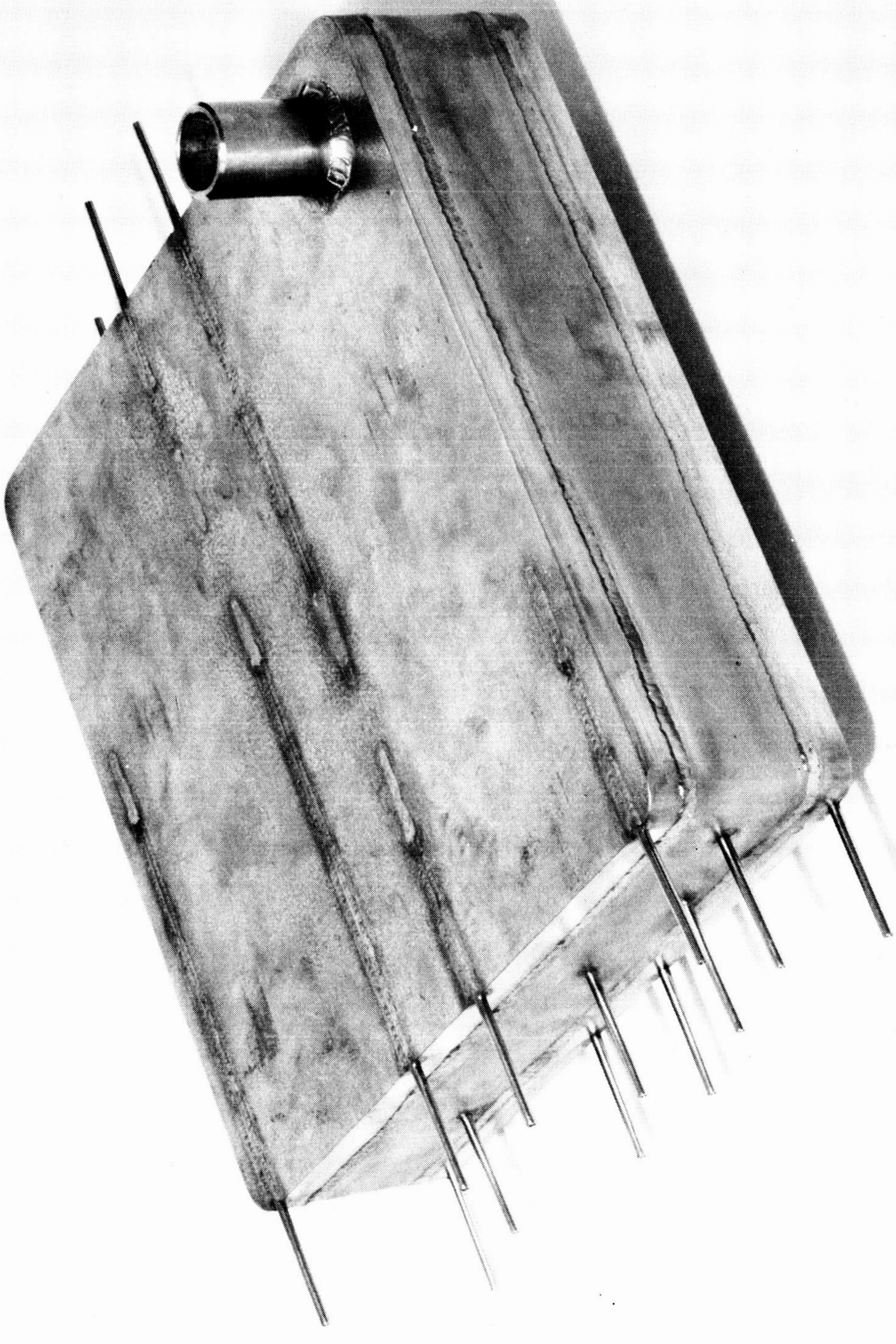
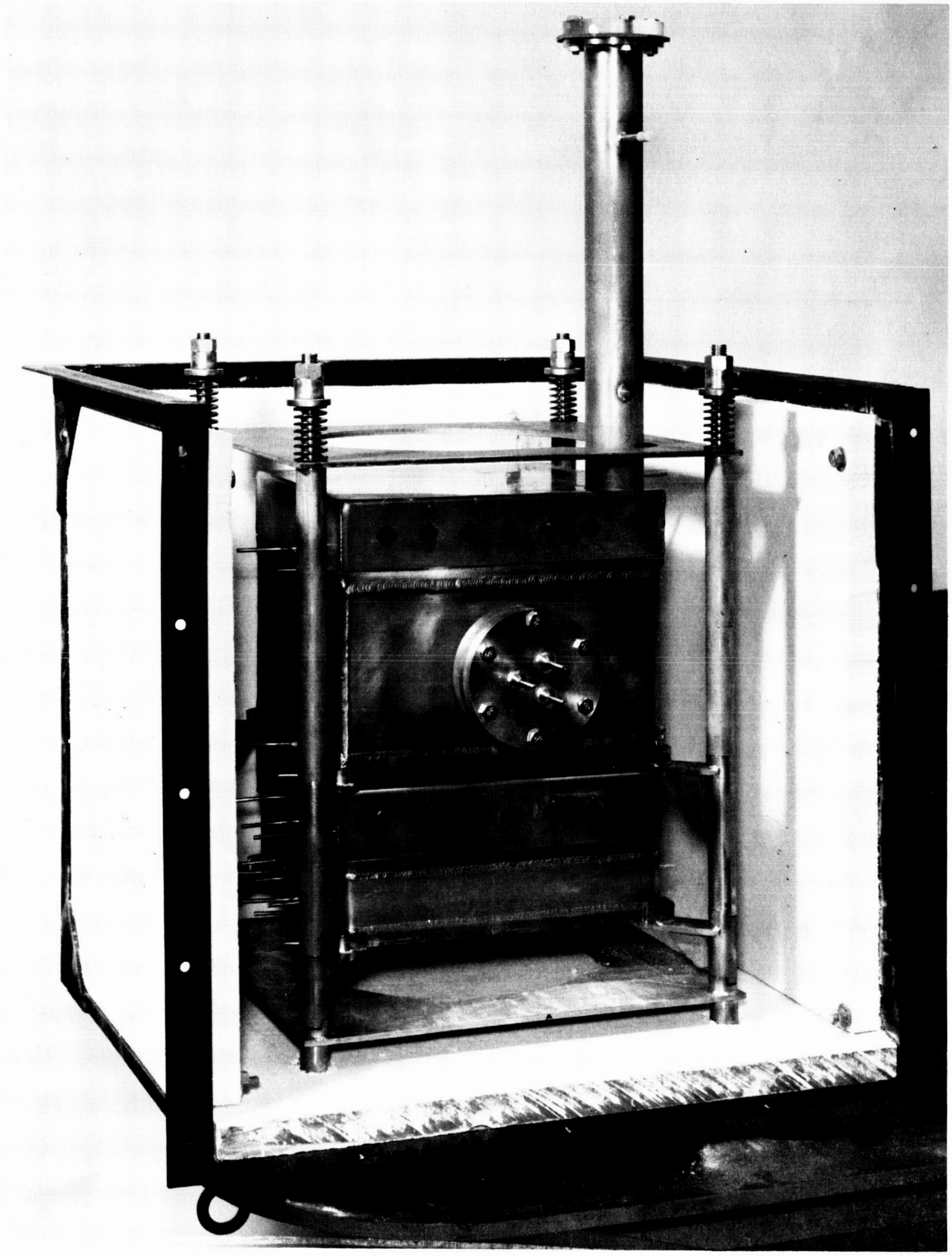

PROPOSED SCHEDULE
PROJECT SCHEDULE FOR AMENDMENT NO. 4 TO CONTRACT NAS 3-2779
WEEKS
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
1. LOADING DEVICE DESIGN
2. LOADING DEVICE FABRICATION
3. PREPARATION OF TEST RIG
4. MODULE DESIGN
A. MODULE A
B. MODULE B
C. MODULE C
D. MODULE D
E. MODULE E
5. MODULE FABRICATION
A. MODULE A
B. MODULE B
C. MODULE C
D. DUMMY NO. 1
E. DUMMY NO. 2
F. MODULE D
G. MODULE E
6. MODULE FILLING & TESTING
A. MODULE A
B. MODULE B
C. MODULE C
D. DUMMY 1
E. DUMMY 2
F. MODULE D
G. MODULE E
7. DATA ANALYSIS
8. NASA APPROVAL OF MODULE E DESIGN
9. COMPUTER CALCULATION OF FINNED SURFACE PERFORMANCE

FIGURE 9



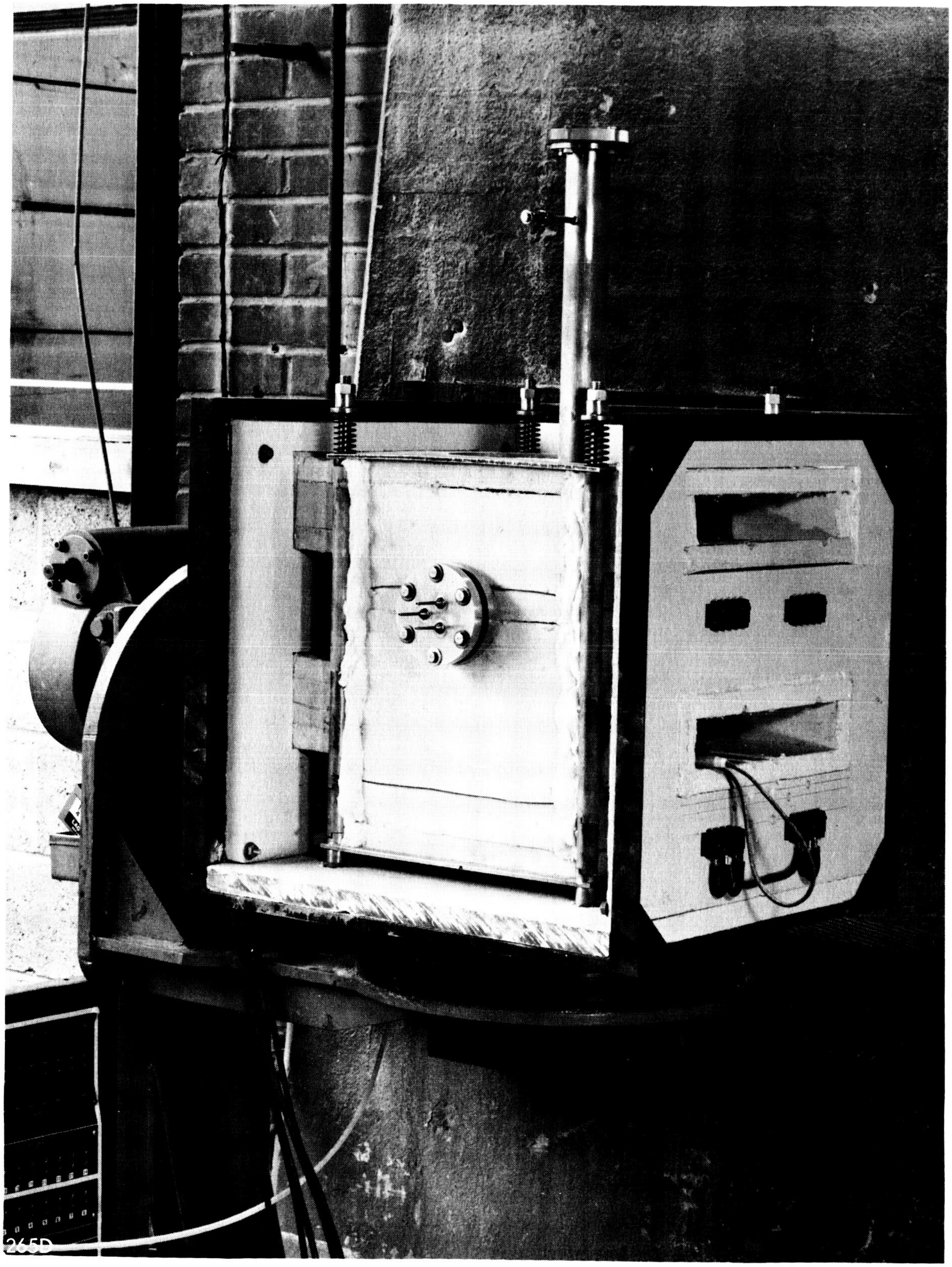
VIEW OF MODULE A

FIGURE 10



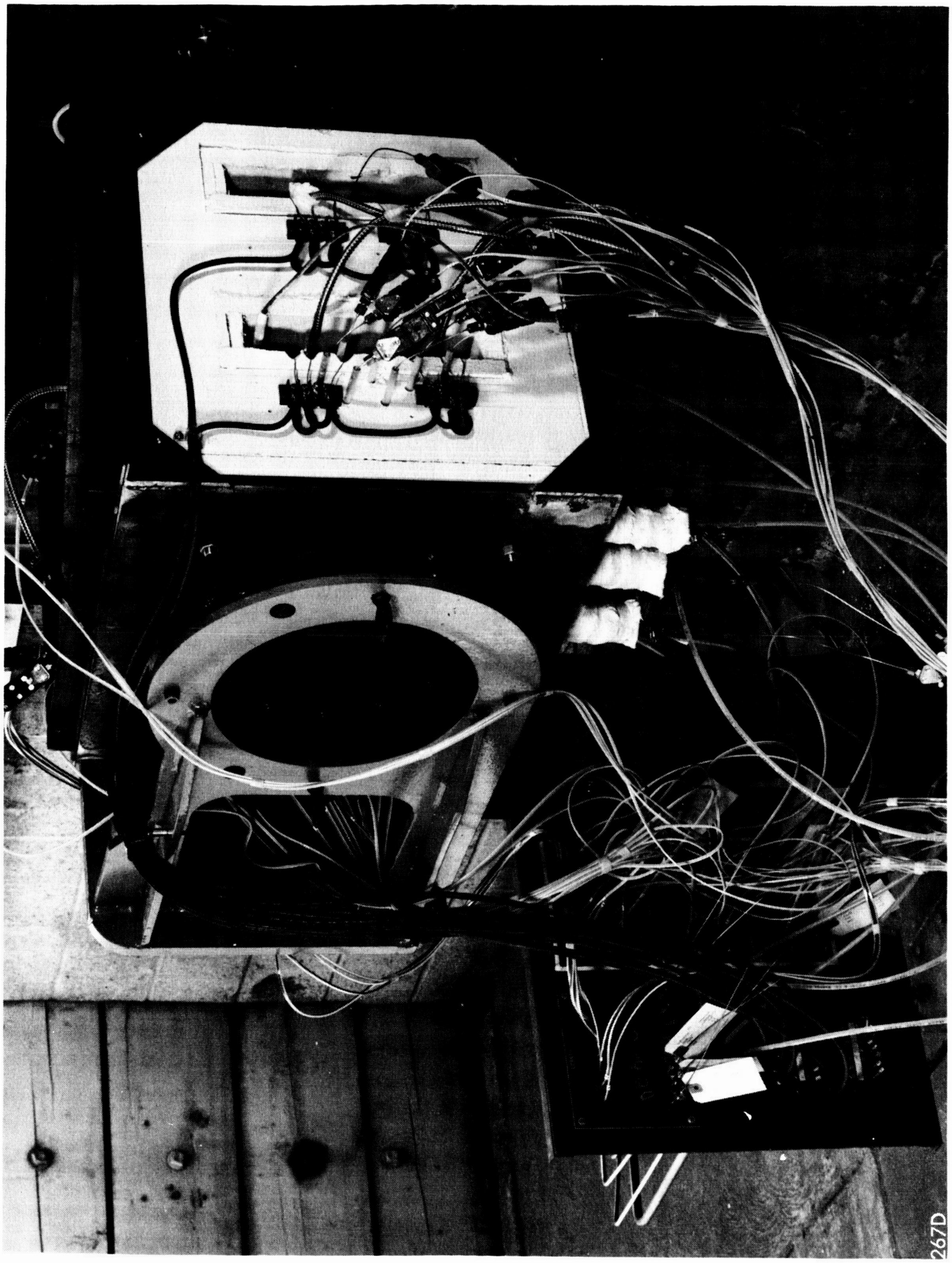
VIEW OF TEST ASSEMBLY

FIGURE 11



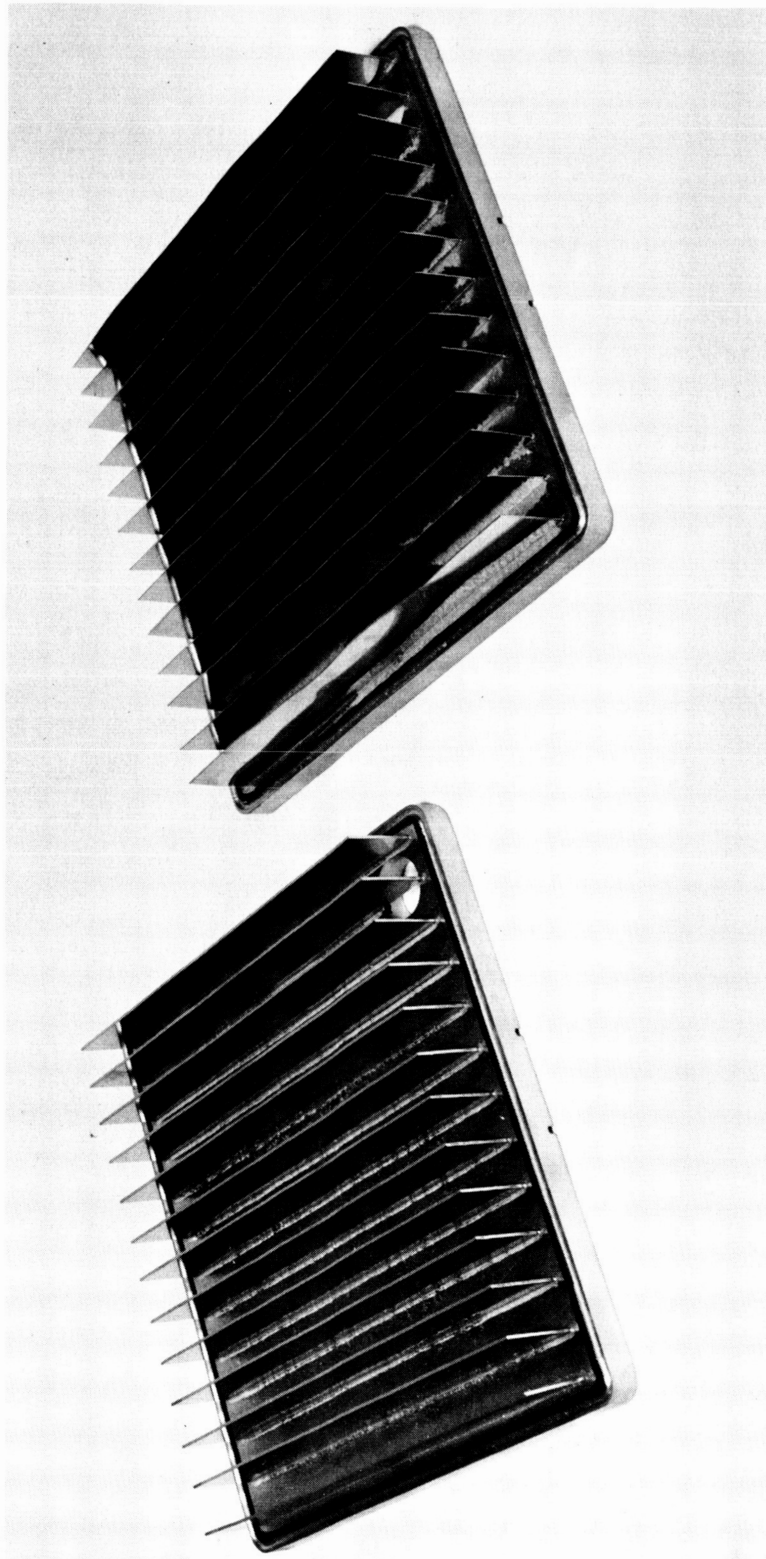
VIEW OF TEST ASSEMBLY WITH HIGH TEMPERATURE
INSULATION INSTALLED

FIGURE 12



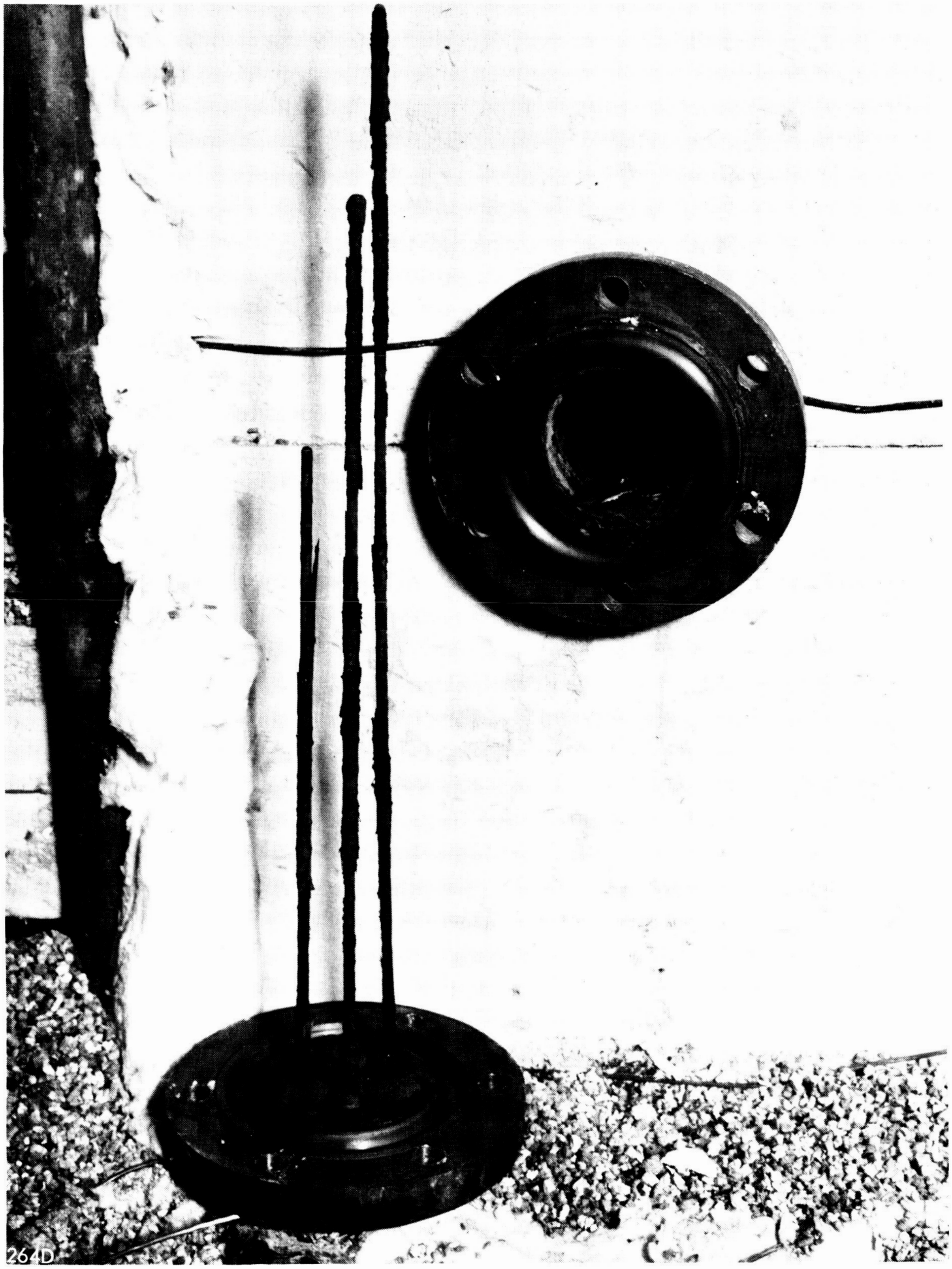
VIEW OF TEST ASSEMBLY IN POSITION FOR MELTING LITHIUM FLUORIDE

FIGURE 13



VIEW OF TOP PLATES OF MODULES B AND C
AFTER INITIAL FIN BRAZING

FIGURE 14



CLOSEUP VIEW OF SCALED PARTS AFTER
AIR LEAK INTO SYSTEM

FIGURE 15

PROJECT SCHEDULE, TASK IV, TWO PERCENT GAS PRESSURE DROP RECEIVER/HEAT STORAGE DESIGN

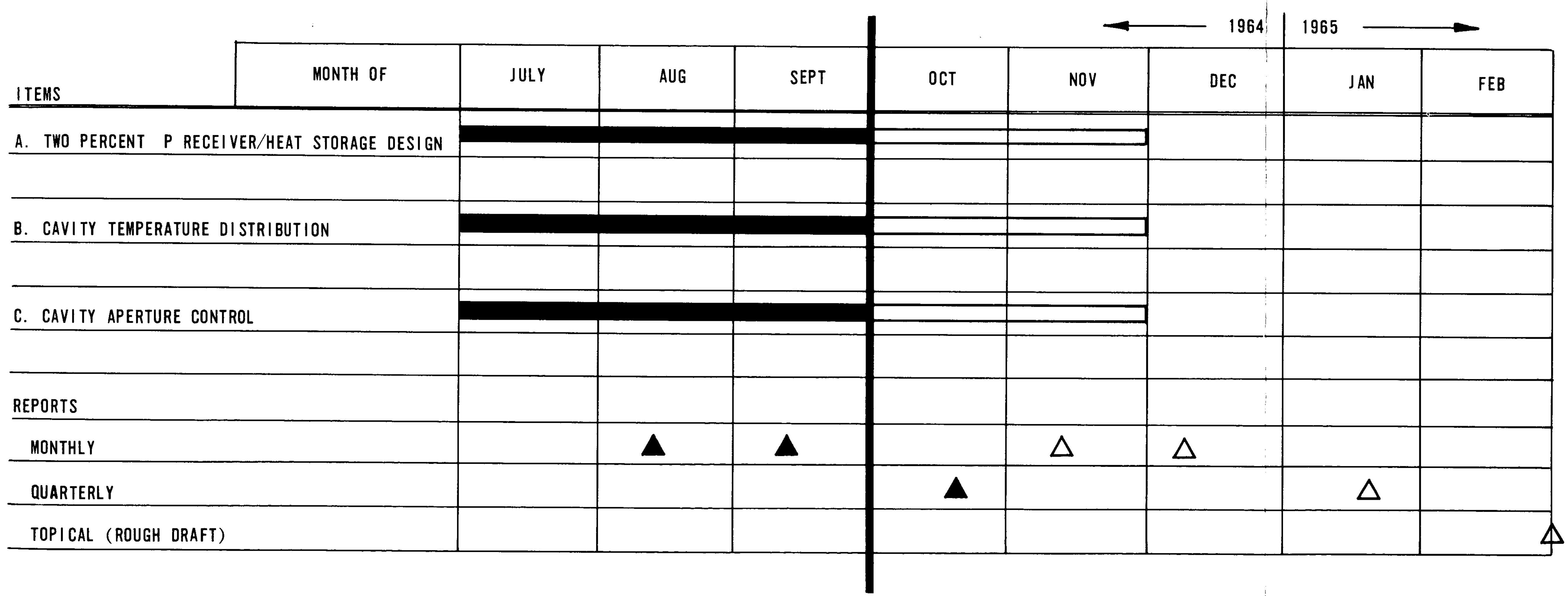


FIGURE 16

VARIATION OF THE TRANSITIONAL REYNOLDS NUMBER IN CURVED TUBES WITH THE RATIO OF TUBE RADIUS TO RADIUS OF CURVATURE

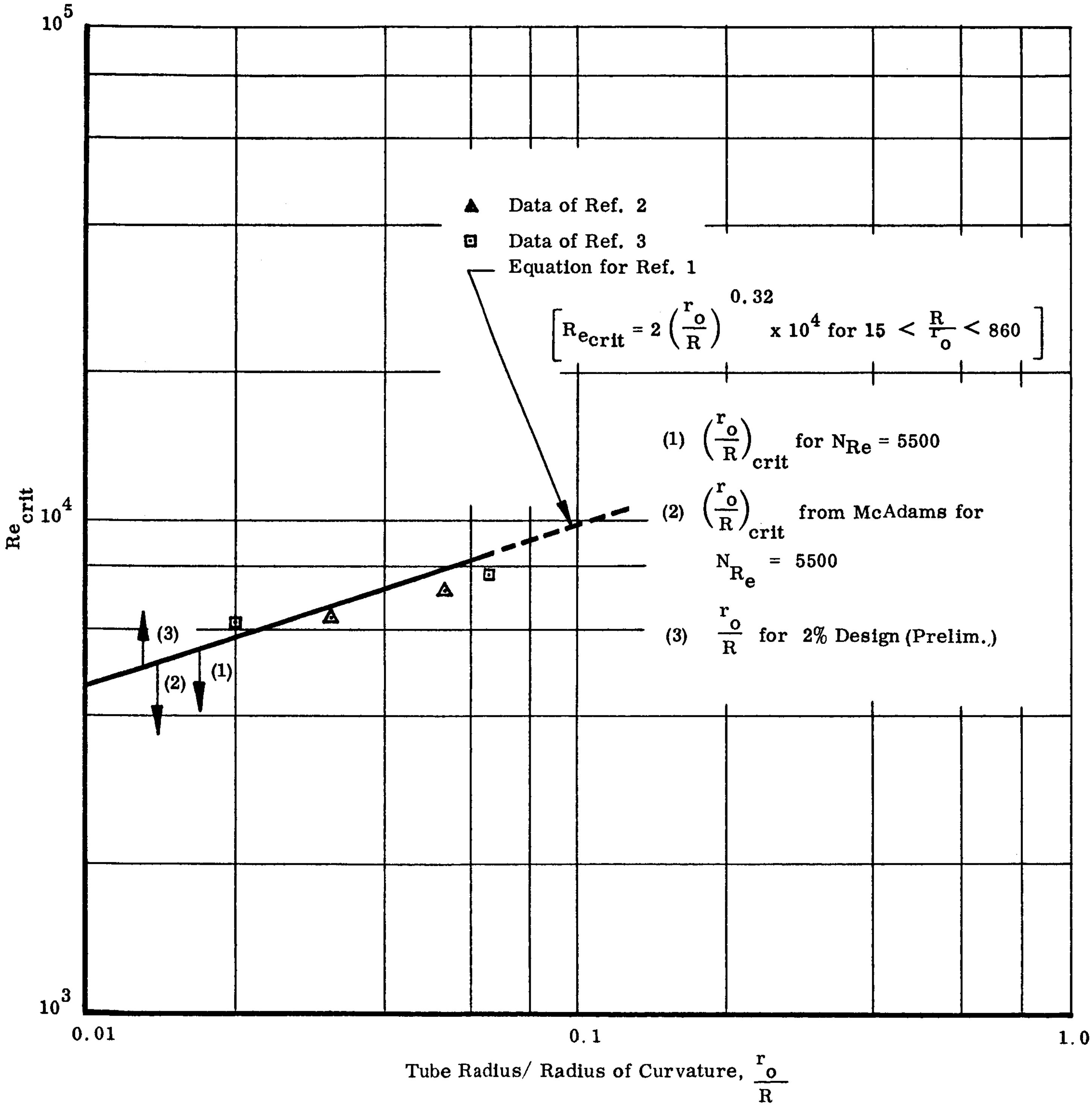
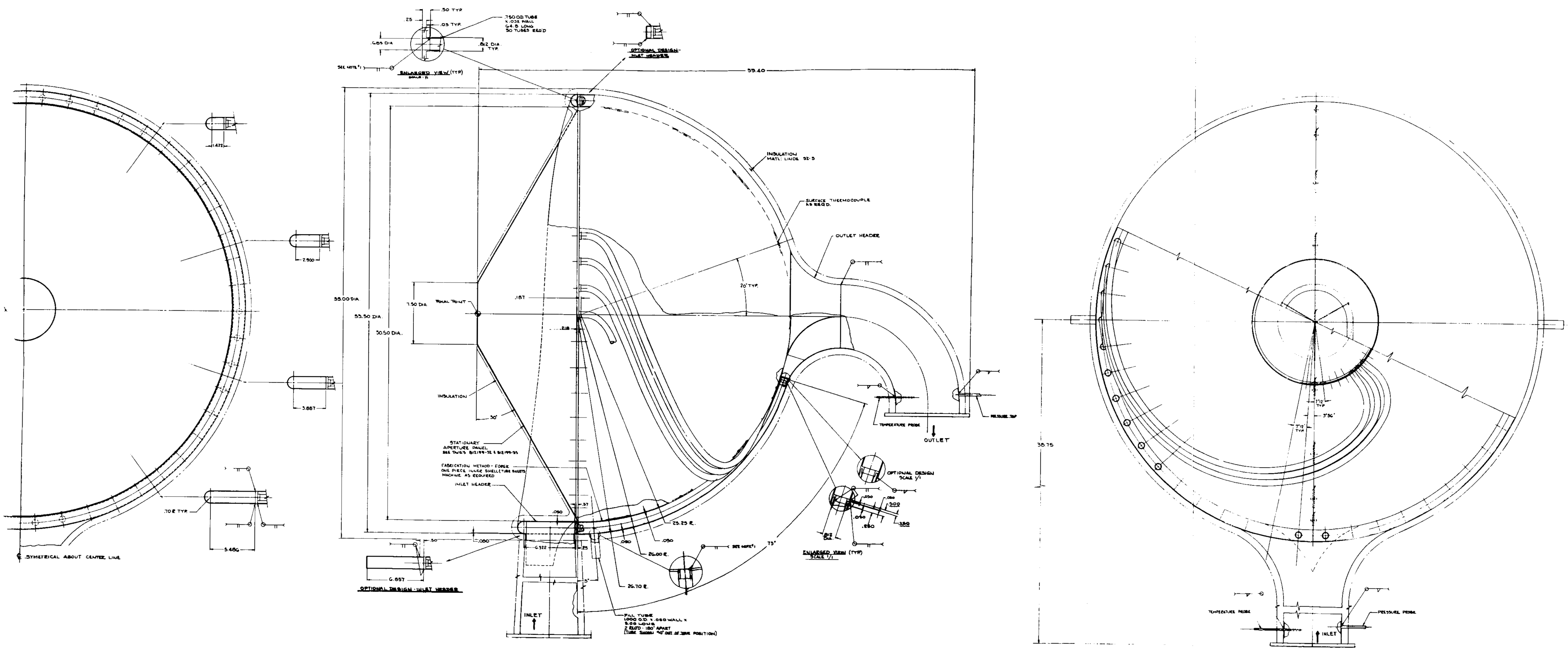
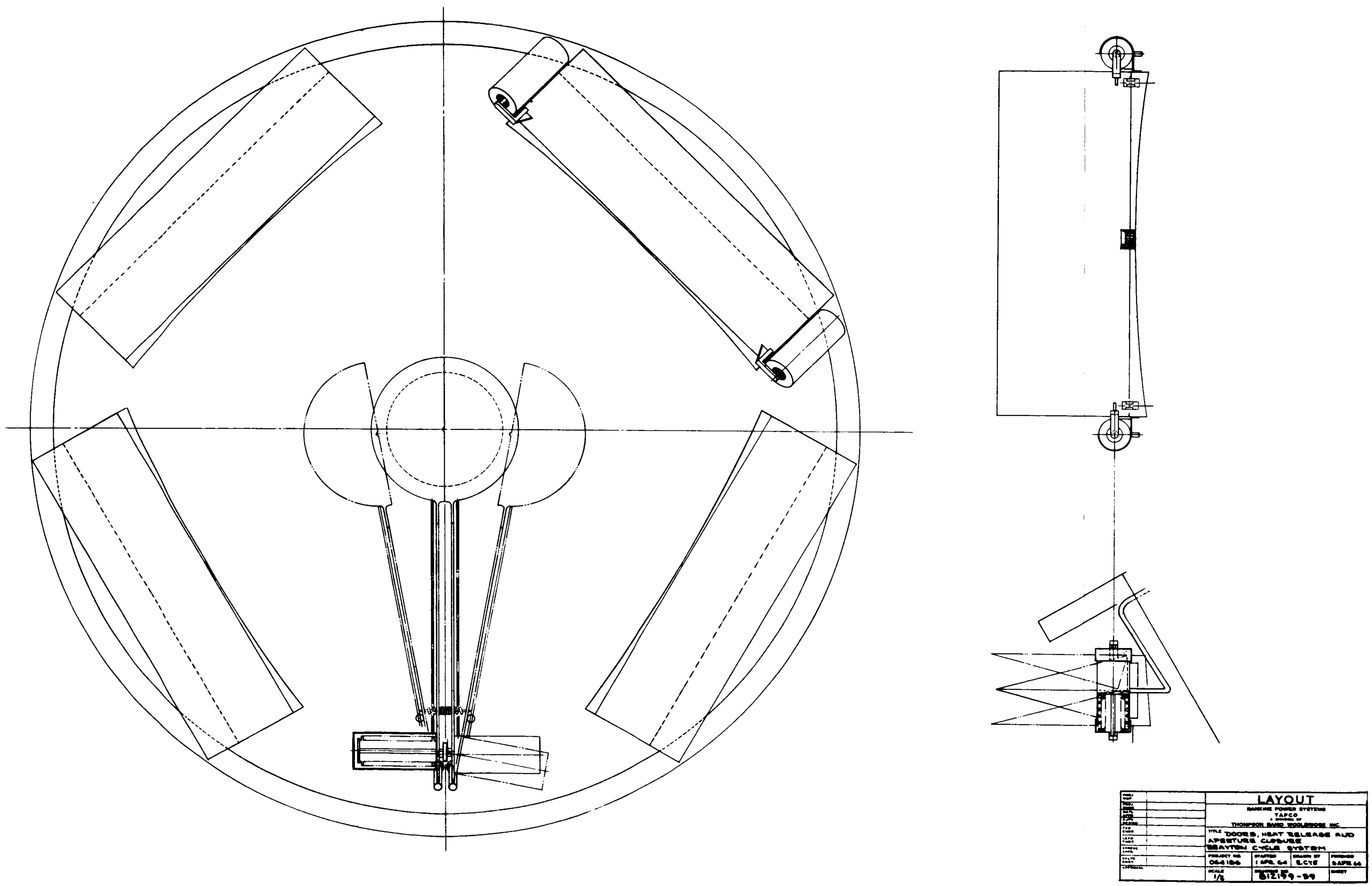


FIGURE 17



CAVITY RECEIVER 300 NM - 30 FOOT MIRROR
BRAYTON CYCLE

FIGURE 18



APERTURE CONTROL ASSEMBLY CONCEPT

FIGURE 19

TYPICAL MELT LINE PATTERN

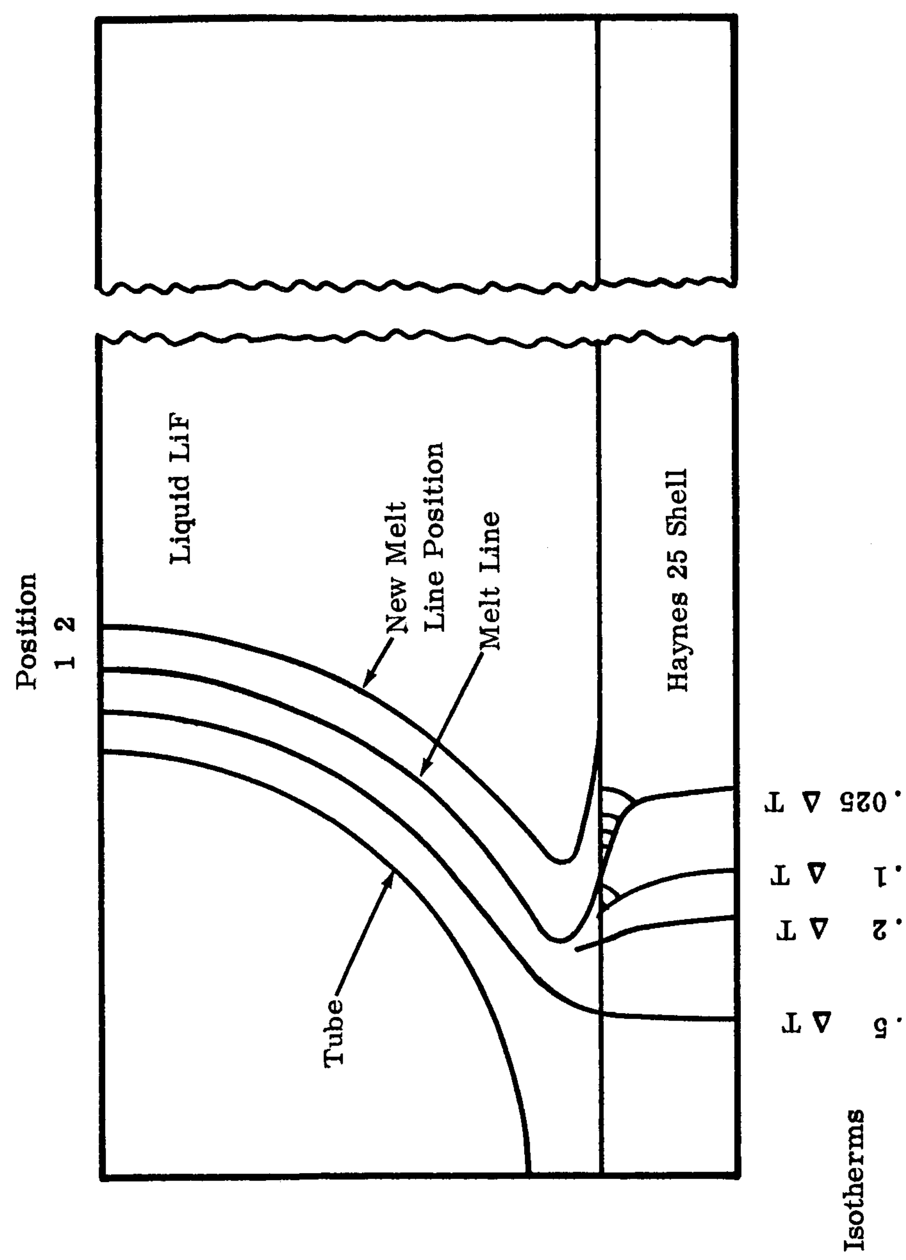


FIGURE 20

ADDITIONAL MELT LINE PATTERN

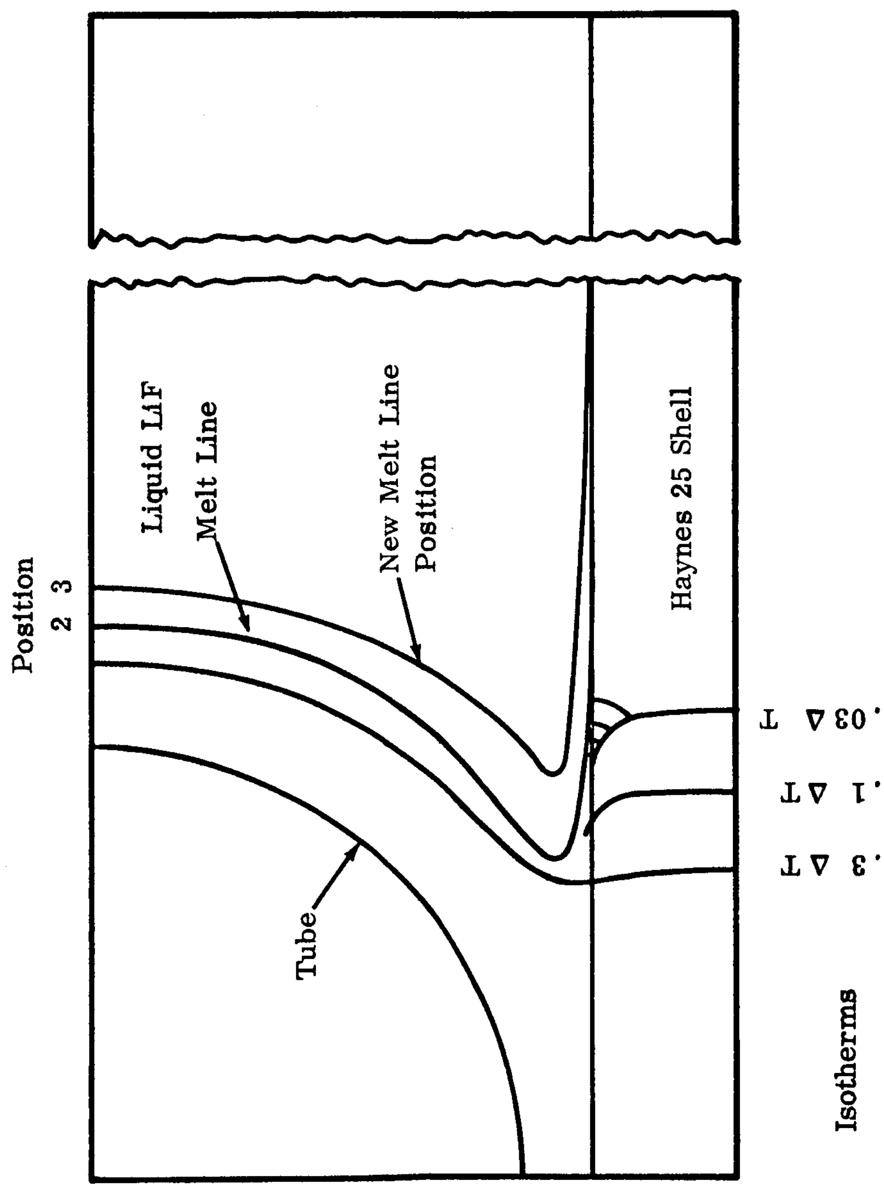


FIGURE 21

VARIATION OF GEOMETRIC RESISTANCE FACTOR
WITH VOLUME OF FROZEN FLUORIDE

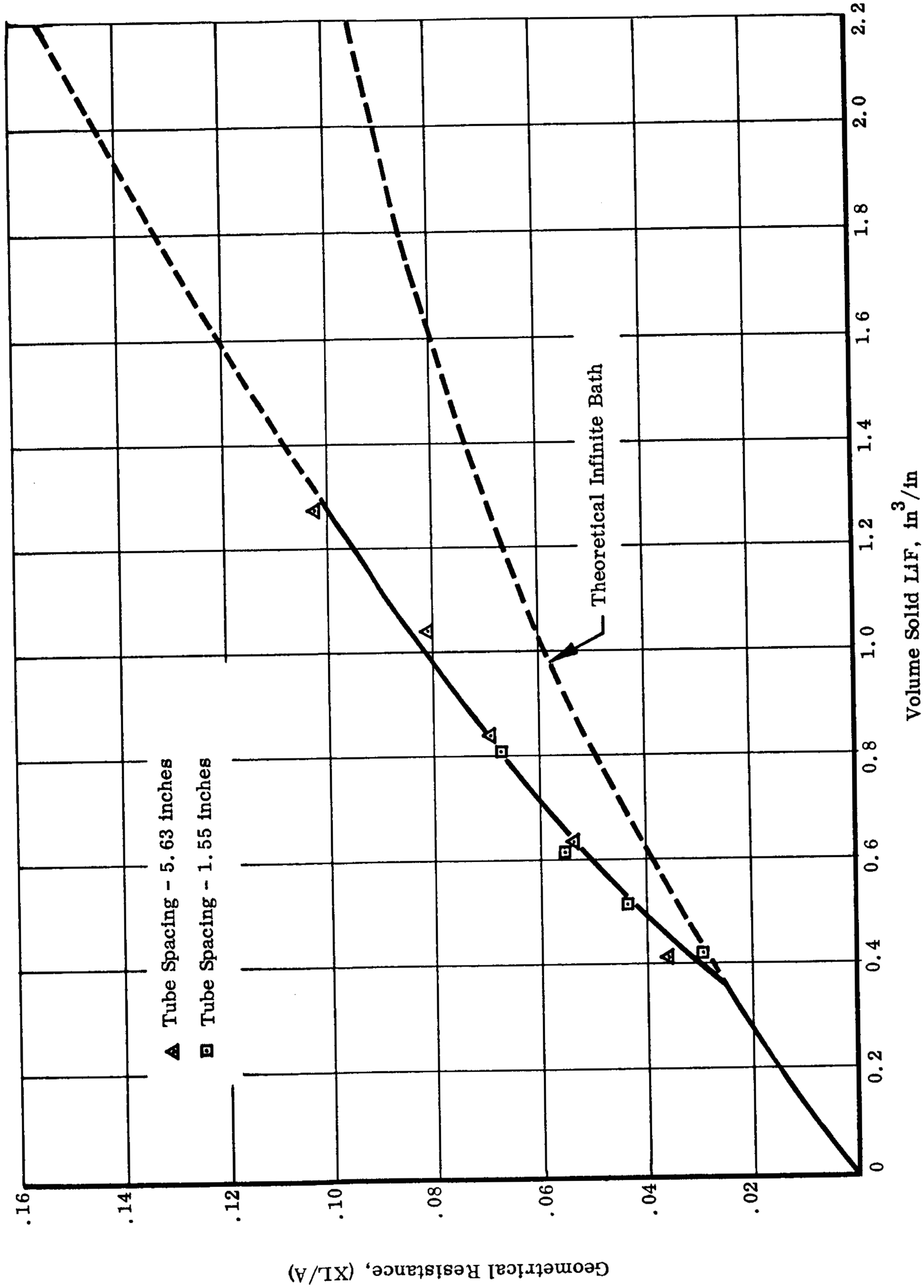


FIGURE 22